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Technology Transfer

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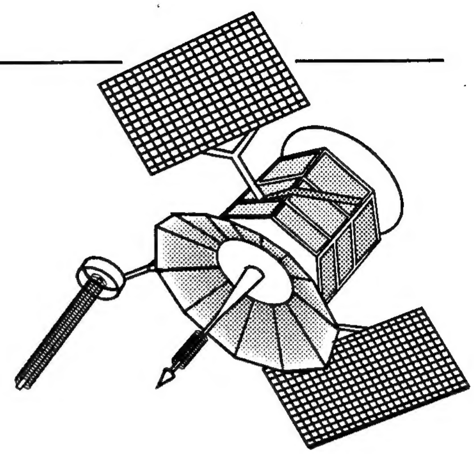

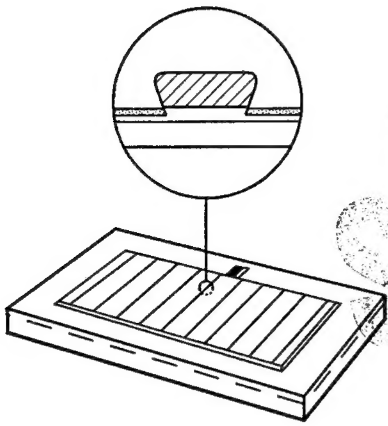

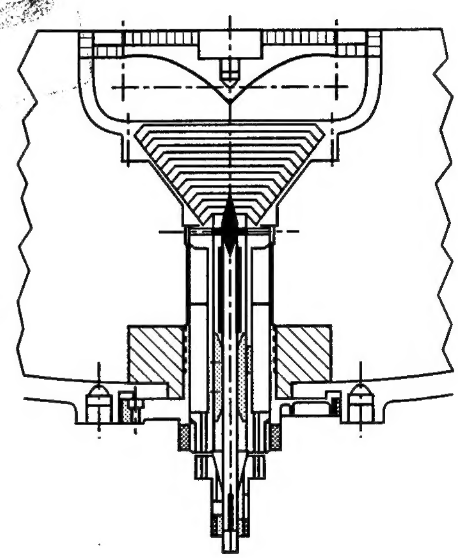

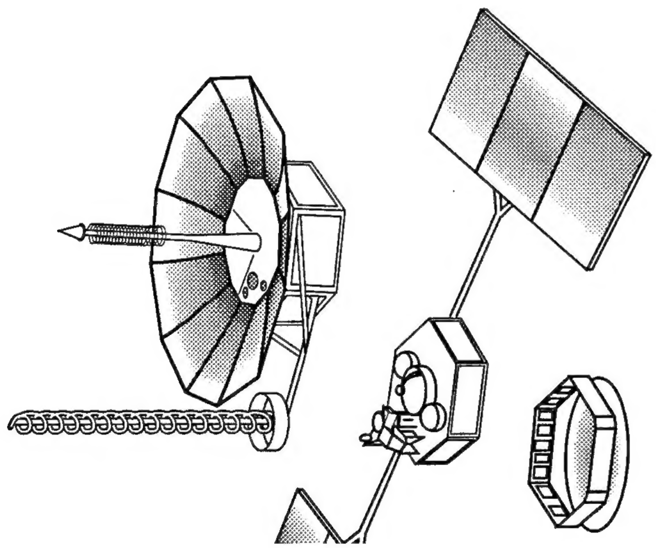

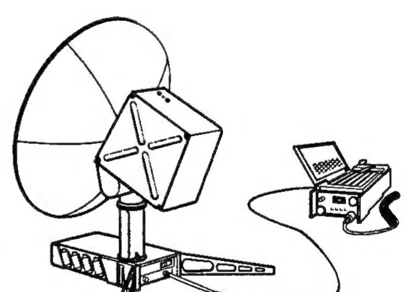

Massachusetts Institute of Technology
Lincoln Laboratory

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FOR THE COMMANDER

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Prepared by Group 17
Library and Information Services

TABLE OF CONTENTS

1. INTRODUCTION

MIT Lincoln Laboratory was established in 1951 by the Massachusetts Institute of Technology at the request of the Department of Defense. Since that time, its mission has been to conduct research and development in support of national defense. Through transfer of technology to the military and civilian sectors, MIT Lincoln Laboratory has made substantial contributions to the national defense and to the Nation's economy. Technology transfer of research and development conducted at Lincoln Laboratory is not a new concept. It has been a key part of the Laboratory's mission since its inception.

2. EXECUTIVE SUMMARY

MIT Lincoln Laboratory is a Federally Funded Research and Development Center (FFRDC). Its principal focus is the development of technology to provide solutions to national problems. While the Laboratory's work is principally supported by the Department of Defense, many technological developments have found application in the civilian sector.

The Laboratory's programs span the full range of technological development: basic research, components and subsystems, feasibility determination, system development, and demonstration. The Laboratory does not produce or implement systems; thus, it has always been important that the work be effectively transferred to those who do. From its outset the Laboratory has recognized the value of making its research results and basic technology available to the entire scientific and technical community. For this reason, technology transfer has been a cornerstone of Lincoln Laboratory's philosophy since its establishment.

Transfer of Lincoln Laboratory's intellectual achievements takes many forms:

1. Assisting military procurement personnel in the development of specifications, and working with industrial contractors to insure successful transfer of technology.
2. Hosting frequent technical seminars and workshops to provide a conduit for technology transfer.
3. Providing briefings and demonstrations for visitors.
4. Publishing classified and unclassified technical reports.
5. Publishing seminal texts that have led to the development of new technical fields.
6. Publishing books and monographs for general distribution.
7. Publishing articles in professional journals.
8. Presenting papers at professional meetings.
9. Publishing the *Lincoln Laboratory Journal.*
10. Patenting, copyrighting, and licensing of inventions and software.
11. Publishing the annual *Unclassified Publications of Lincoln Laboratory.*
12. Utilizing techniques and hardware developed at Lincoln Laboratory in the design of military systems.

Other examples of successful technology transfer that are beneficial to the national economy are the large number of spin-off companies that have been started with Lincoln-developed technology, and the large number of patents issued to Lincoln Laboratory Staff. This report has been assembled to indicate the scope of Lincoln Laboratory's activities. It is not intended to be a complete list of all the activities that have transpired.

This report provides statistics and brief descriptions of the various technology transfer activities mentioned above. The mission areas covered are Strategic Offense and Defense, Satellite and Laser Communications, Space Surveillance, Surface and Air Surveillance, Advanced Electronics Technology, High Energy Laser Beam Control Technology, and, in the civilian sector, Air Traffic Control.

3. TECHNOLOGY TRANSFER BY MISSION AREA

The Laboratory's initial research was focused on very large defense radar systems. Subsequently, research broadened into such areas as ballistic missile defense, satellite communications, solid state technology, air traffic control, advanced computer technology, and optics.

3.1 RECENT ACTIVITIES (1970-1989)

3.1.1 Strategic Offense and Defense

Technology

1. *Active Replication of Re-entry Vehicles:* Lincoln Laboratory pioneered the principles of electronically replicating the radar observables of re-entry vehicles for the Active Decoy Phase I program. Several electronic replica decoys were fabricated and flight tested by the subcontractor under the direction of Lincoln Laboratory. User agency: Air Force Ballistics Systems Division. Industry developer: GE.

2. *Telemetry from a Plasma Effects Decoy:* The plasma effects decoy is a re-entry vehicle designed for plasma data collection. It has a series of measurement circuits and a telemetry channel for transmitting data from re-entry vehicles to a ground-tracking radar. The telemetry package will be used in future test flights to study further the pyrotechnic concept. User agency: Air Force Ballistics Systems Division. Industry developer: Acurex.

3. *Plasma Prediction and Measurement:* As part of the Re-entry Systems Program, codes have been developed for predicting the electron densities in the plasma sheath that surround decoy-sized bodies during re-entry. These codes, which have been used in electromagnetic method-of-moment codes that calculate the radar scattering properties of the sheath, have been made available to industry through the sponsor. Analytic and experimental results were presented at an Air Force Ballistics Systems Division Plasma Workshop. Sponsor: Air Force. User agency: Air Force Ballistics Systems Division.

4. *Aerosol Concept for Optical Infrared Masking:* Lincoln Laboratory, under the Re-entry Systems Program, developed an aerosol concept for optical IR (infrared) masking. The aerosols alter the infrared signatures of space objects to deny their observations by passive optical sensors. This concept was transferred through technical reports and industrial seminars. Sponsor: Air Force. Industry user: Air Force Countermeasure Community.

5. *Ferrite Phase Shifters for Array Radars:* A variety of novel designs for waveguide ferrite phase shifters were implemented by Lincoln Laboratory. This work included several innovative developments in ferrite materials and processing that led to substantial benefits in improved device performance at lower cost. In each case, the theory and experimental results were published in the open literature, and technology details were adopted in product development by subcontractors, where they remain industry standards. Sponsors: Army and DARPA. Industry developers: Raytheon, Trans-Tech., Ampex.

6. *Submillimeter-Wave Radiometry of Rocket Plumes:* Lincoln Laboratory developed a heterodyne radiometer for measuring the temperature of water vapor from molecular absorption lines at submillimeter (~0.5 mm) wavelengths. This apparatus was used to determine the radiometric absorption signatures of simulated high-altitude rocket plumes, as an alternative to the more conventional near-infrared emission signature techniques. Sponsor: Army. Industry user: Millitech.

Techniques

1. *Carbon-Loaded Teflon:* A method of fabricating carbon-loaded Teflon was developed at Lincoln Laboratory. Carbon-loaded Teflon was used in the Active Decoy Program as a heat-shield material with good microwave attenuation properties. The preparation method, a description of dielectric properties, and the theoretical model that accounts for the dielectric properties of the material were transferred to industry. Sponsor: Air Force. Industry developers: Acurex, Avco, United Research Technology.

2. *Ablative Heat-Shield Materials:* The Laboratory developed the fabrication of ablative heat-shield materials with controlled dielectric properties. Industry developers: Zoltek, Avco.

3. *Slender Nose Tips:* The Laboratory developed aerodynamic thermal and mechanical designs for slender nose tips. Industry developer: GE used these designs in their Active Decoy Program.

4. *Radar Cross Section Modeling:* Several electromagnetic analytic codes were developed under the Active Decoy and Penetration Aid Technology Programs. The codes, with experimental results, were transferred to industry. Sponsor: Air Force. Industry developer: Atlantic Aerospace.

5. *Re-entry Particle Plume Code:* Under the Re-entry Systems Program, Lincoln Laboratory developed a hot-particle plume code that predicts IR signatures. It was incorporated into the Army's OSC (Optical Signatures Code) and has been used to predict re-entry body signatures. Sponsor: Air Force. User agency: U.S. Army Strategic Defense Command.

6. *Magnesium-Teflon Flare Chemistry:* Lincoln Laboratory investigated the use of Magnesium-Teflon combustion chemistry to obtain a large IR signature for masking. A theory of the combustion physics that would predict the IR signature was developed and transferred to the Air Force and the Pyrotechnic Countermeasure Program contractors. Sponsor: Air Force. Industry developers: Acurex, Morton-Thiokol, Rocketdyne.

7. *Optical Reference Sphere and Coating:* Optical reference spheres were flown during sounding-rocket and satellite tests to help calibrate on-board sensors. The technology for producing the optical coatings and the measurement techniques for characterizing surface optical properties were made available to industry and government agencies in an Air Force/Army-sponsored workshop hosted by Lincoln Laboratory. Sponsors: Air Force and SDIO. User agencies: Air Force, Army, SDIO.

8. *Passive Optics Techniques:* Lincoln Laboratory is using telescopes to measure the physical characteristics of targets. Some of the techniques relating to infrared sensors have been formulated into computer algorithms that operate in real time. Sponsor: Army.

9. *LWIR (Long Wavelength Infrared) Signal Processing:* An adaptive window technique was developed for processing new data automatically and for removing background fluctuations from nonstationary backgrounds. This technique, which improves sensor measurement precision for space-based platforms, was applied to data gathered during the DOT (Designating Optical Tracker) experiment and HOE (Homing Overlay Experiments) conducted by the U.S. Army. Sponsors: Air Force and Army.

10. *LWIR Sensor Calibration:* Lincoln Laboratory developed and applied a new technique for calibrating LWIR sensors in-flight. This technique, demonstrated on the Delta 181 mission, provides detailed calibration information that cannot be obtained presently at low irradiance using ground-based facilities. Sponsors: Air Force and Army.

11. *Target Reflectivity Analysis — Analytic Model and Code:* An analytic and predictive technique was developed for interpreting target reflectivity data as a function of wavelength and angle in terms of target electrical properties, such as complex dielectric coefficient for a number of layers of varying thickness. This connection is made in terms of Fresnel equations. The technique has been used for interpolation of materials measurements, which are very difficult to make at grazing incidence. It has also been used for optical signature modeling. Sponsor: Air Force. Industry developers: Surface Optics, Teledyne Brown Engineering.

12. *Debris Modeling:* Lincoln Laboratory developed a model that analyzes debris caused by the impact destruction of a booster or re-entry vehicle. The model gives the number of pieces in a given size range and also estimates their translational and rotational velocities. Industry developers: Nichols Research Corp., XonTech.

13. *Scan-to-Scan Correlation Algorithm:* An algorithm was developed at Lincoln Laboratory that associates a sequence of scans from an optical sensor into tracks on individual and clusters of targets. It can handle a variety of targets, target densities, measurement resolutions, sensor frames, etc. The algorithm has become the industry standard and is used in probe- and satellite-based sensors. Industry developers: Nichols Research Corp., Teledyne Brown Engineering.

14. *Miss Distance Analytic Model:* A simple analytic model was developed for calculating interceptor miss distance as a function of sensor accuracy, acquisition range, missile response time, missile acceleration, closing velocity, and several other parameters. It provides simple scaling laws and has been widely used in the ballistic missile defense community to guide application of more detailed simulations. The model was developed for re-entry intercepts but has also been applied to Brilliant Pebbles in the boost phase. Industry developers: Martin Marietta, SAIC.

15. *GBR (Ground-Based Radar) Discrimination Algorithm:* As part of the SDIO (Strategic Defense Initiative Organization) Program, Lincoln Laboratory has been working on ground-based radar for midcourse and terminal defense. Discrimination algorithms for both re-entry and midcourse analyses have been transferred to Raytheon. Sponsors: SDIO and Army. Industry developer: Raytheon.

16. *High Resolution Radar Imaging:* Lincoln Laboratory has been instrumental in the development of high resolution radar imaging for earth satellites and strategic system components. The ALCOR

(ARPA Lincoln C-Band Observables Radar) was used to acquire and analyze data on near-earth satellites. Development of a new long range capability at the Haystack Observatory now provides data on satellites out to synchronous orbit. Subsequently, the use of high resolution imaging techniques was extended to strategic targets. Sponsor: Air Force.

Systems

1. *COBRA DANE Radar:* The Laboratory assisted the Air Force in the development of the COBRA DANE radar, a land-based radar system which acquires and tracks a number of objects associated with missile launches. Sponsor: Air Force. Industry developer: Raytheon.

2. *COBRA JUDY Radar:* In the late 1970s and early 1980s the Laboratory assisted both the Air Force and Army in the specification, acquisition, and data processing developments for the COBRA JUDY radar. This ship-borne radar is used for tracking Soviet ballistic missile tests. Sponsors: Air Force and Army. Industry developer: Raytheon.

3. *OAMP (Optical Aircraft Measurements Program):* This program created COBRA EYE, an airborne, three color, passive infrared sensor for accurate measurement of the temporal and spectral radiometric properties of missile systems. The data gathered by the COBRA EYE system will be utilized in the development of discrimination algorithms for use in Ballistic Missile Defense applications. The sensor is installed on a USAF RC 135X that is flown from the 6th Strategic Reconnaissance Wing of the SAC (Strategic Air Command) based in Alaska. Data from the system are sent to Lincoln Laboratory for calibration and formatting before they are distributed to other designated organizations. Sponsor: Army.

4. *KREMS Project:* In the 1960s Lincoln Laboratory developed sensors and data processing systems for the PRESS (Pacific Range Electromagnetic Signature Studies) Project. (See PRESS Project section on p. 31.) Some of the recent sensors developed were: ALCOR (1970), and MMW (Millimeter Wave) (1983). Sponsors: DARPA and Army. User agencies: Army, Navy, Air Force, NASA, and NSF. Industry sensor developers: OTM, GE, GTE. Industry users: TRW, XonTech, Ford Aerospace, Lockheed, GE, GTE, Avco.

3.1.2 Satellite and Laser Communications

Technology

1. *Spatial Acquisition and Tracking:* The issue of spatial acquisition and tracking of the very narrow laser beams is of paramount importance in laser communications. Lack of a well engineered spatial tracking system has hindered progress in some space laser communications efforts. The Lincoln Laboratory spatial acquisition/tracking system designed for LITE (Laser Intersatellite Transmission Experiment) is a robust system. The technology requirements and system engineering rationale behind the requirements were transferred to Perkin-Elmer during the LITE program. Industry developer: Perkin-Elmer.

Techniques

1. *FEP (FLTSAT EHF Package) and EHF Test-Bed:* The Laboratory's EHF FEP test-bed activities demonstrated that highly protected satellite communications could be provided to numerous small, mobile terminals through the use of (1) wide-band, spread spectrum techniques in the extremely high frequencies (20 to 45 GHz), (2) satellite-based multiple channel signal processing, (3) access control, and (4) circuit switching. FEP has many sophisticated on-board signal processing capabilities such as demodulation and remodulation of user data and control messages; corrective responses to terminal uplink time acquisition and tracking probes; and encryption, encoding, and interleaving of command and telemetry links. The technologies from FEP and its EHF test-bed have been incorporated into the MILSTAR satellite. A few examples of technology transfer include:

   a. Low-data-rate EHF waveform transmission standards which established the signal processing needs for MILSTAR satellites and the Army, Navy, and Air Force terminals which will use them.

   b. Low-power multiple-channel satellite uplink demodulators using SAW devices.

   c. Uplink acquisition processor designs for anti-jam performance.

   d. EHF up- and down-conversion techniques.

   e. Satellite-based access controller protocols for robust, dynamic, demand-assigned service.

   f. Uplink ranging concepts for innovative orbit determination by mission-control terminals.

   g. Anti-jam downlink acquisition and ranging techniques.

   h. Lightweight, efficient, EHF antenna designs for satellites and terminals.

   i. High-power (>20-W), 20-GHz downlink TWTAs.

   j. Test procedures for pre- and post-launch evolutions of complicated EHF satellites and terminals.

   k. Weather-related link availability computer program.

2. *MDR (Medium Data Rate)/HDR (High Data Rate) Communications:* Lincoln Laboratory developed frequency plans that accommodate, without interference, the large number of required LDR (low-data-rate), MDR, and HDR uplink and downlink carriers. At the request of Air Force Space Systems Division, the candidate frequency plans were briefed to the DSCS (Defense Satellite Communications System) Follow-On Study contractors. Sponsor: Air Force Space Systems Division. Industry users: GE, TRW, Hughes.

3. *MDR EHF Transmission Waveforms:* Lincoln Laboratory assembled a MDR signal-processing test-bed to demonstrate the performance of MDR EHF transmission waveforms. The results of these demonstrations have impacted DSCS efforts to define transmission waveforms. User agency: Air Force Space Systems Division.

4. *Stitchweld:* As a part of the FLTSAT EHF Package, Lincoln Laboratory developed a process for stitchweld circuit board fabrication that eliminated earlier reliability problems. New procedures include a modified machine operating cycle, additional process monitors, and special surface preparation for the welding pins. Sponsor: Air Force. Industry developer: Moore System Stitchweld.

5. *EHF Down-Conversion Scheme:* Lincoln Laboratory developed a double conversion scheme that down-converts a frequency-hopped 44-GHz signal to a low intermediate frequency in a way that intermodulation products produced by signals at the band edges are easily filtered out of the channel. The scheme was transferred to TRW. Sponsor: Air Force. Industry developer: TRW.

6. *Weather Computer Program:* Using weather statistics, Lincoln Laboratory developed a computer program that predicts the expected link outage time from rain attenuation. The program output is a global map showing link outage time per year for links with a given margin. Sponsor: Air Force. Industry developer: Lockheed.

Components

1. *44/20-GHz Dual-Frequency Horn:* An antenna was developed for the Advanced Development Model of the SCOTT (Single Channel Objective Tactical Terminal) satellite communications terminal (also developed by Lincoln Laboratory). It combined 44- and 20-GHz ports into a single circularly polarized aperture, which resulted in a very small antenna. The design was patented by the Air Force and marketed commercially. Sponsor: Air Force. Industry developers: Alpha Industries, Raytheon.

2. *20- and 44-GHz Earth-Coverage Horns:* These horns were developed for the FLTSAT EHF Package. The designs were later transferred to TRW, to meet the gain requirements of certain earth-coverage antennas. Sponsor: Air Force.

3. *4-Lens MBA (Multiple-Beam Antenna):* This EHF antenna design gives communications satellites ~3 dB more gain than a single lens design. It is used by the MILSTAR payload contractor in agile beam uplink and downlink antennas. Sponsor: Air Force.

4. *Waveguide Lens MBA:* This antenna, capable of producing 61 beams, was developed and tested at Lincoln Laboratory as part of a SHF antenna nulling system. The antenna design was adopted by GE for incorporation into the DSCS-III communications satellite design. Sponsor: Air Force. Industry developer: GE.

5. *Beam Area Coverage MBA:* This mechanically steered satellite uplink receiver antenna operates at 44 GHz. It is intended for use with a nulling system and could provide high gain service to a theatre-of-operations with the capability of nulling antennas within the theatre. Sponsor: Air Force. Industry developer: TRW.

6. *Adaptive EHF (44-GHz) Uplink Satellite Antenna:* Lincoln Laboratory designed an antenna that generates multiple uplink beams, supports dynamic repositioning of the coverage areas, and discriminates against jammers as close as 50 mi to a user. It weighs less than 100 lb and uses 100 W. User agency: Air Force Space Systems Division.

7. *High-Power, Reliable 20-GHz Downlink Antenna/Transmitter Assembly:* Lincoln Laboratory's concept for an agile, high-power, reliable 20-GHz downlink antenna/transmitter assembly employing highly efficient solid state transmitter modules has drawn interest from the Air Force. User agency: Air Force Space Systems Division.

Systems

1. *LES (Lincoln Experimental Satellite) Program:* The Laboratory, through the LES Program, designed, built, and flew eight experimental communication satellites. The new technology developed under the program was transferred to industry and found application in a number of satellite communications systems. Sponsors: Air Force, Navy, Army, and DCA (Defense Communications Agency). Example systems (together with the industry developers of the corresponding satellites) include:

AFSATCOM and FLTSATCOM systems at UHF

TACSAT (Tactical Satellites), GAPFILLER, LEASAT (Lease Satellite), and UFO (UHF-Follow-On) satellites — Hughes

FLTSAT satellites — TRW

DSCS-III satellites (single channel transponder) — GE

DSCS (Defense Satellite Communications System) at SHF

DSCS-III satellites (multiple-beam antennas) — GE.

2. *EHF Nulling System:* Lincoln Laboratory developed and demonstrated a brassboard 4-channel EHF antenna nulling system. TRW applied the techniques and design principles to produce a preproduction model of a 16-channel system. Sponsor: Air Force. Industry developer: TRW.

3. *TATS (Tactical Transmission System):* Lincoln Laboratory developed the system designs for interference-resistant, simultaneous-multiple-access satellite communications. TATS handles teletype and vocoded traffic. Sponsor: Air Force. Industry developer: GTE Sylvania.

4. *SCOTT ADM (Single Channel Objective Tactical Terminal — Advanced Development Model):* This is a ground terminal for the MILSTAR satellite system which provides highly robust, anti-jam communications with the MILSTAR system. Sponsor: Army. Industry developers: Magnavox, Steinbacher, Alpha Industries, Raytheon.

5. *Advanced SCAMP (Single Channel Advanced MILSTAR Portable Terminal):* Lincoln Laboratory has been collaborating with industry to develop a man-portable, easy-to-use, low-cost, anti-jam SATCOM terminal for tactical fighting forces. The resulting technology involves a 2-ft petal antenna useful at EHF, a 2-axis communication antenna pedestal, and a miniature EHF transmitter. Sponsor: Army. Industry developers: Harris, MPC, Avantek.

Laser Communications

1. *Techniques:*

   a. *Diode Laser Power Supply and Temperature Control* — In applications involving coherent optical communications, precision current and temperature control must be maintained. Typical commercial power supplies and thermal controllers are too noisy; therefore, researchers resorted to specialized in-house designs for their needs. By adapting designs created by Lincoln Laboratory for the LITE (Laser Intersatellite Transmission Experiment) Program, a contractor hopes to provide versatile precision temperature and current controllers to the technical community. Sponsor: Air Force. Industry developer: Newport Research Corp.

2. *Components:*

   a. *Double Balanced Mixer Front End* — This is a coherent optical receiver architecture that offers near theoretical minimum front-end noise performance. The architecture is suitable for a wide variety of applications including optical communications and coherent laser radar. Sponsor: Air Force. Industry developer: Schwartz Electro-Optics (license under negotiation).

   b. *LITE (Laser Intersatellite Transmission Experiment)* — Lincoln Laboratory is responsible for all the system engineering of this experiment. Seminars have been held detailing the various aspects of the LITE program technology. Future seminars will focus on the space qualified LITE Transmitter and Diagnostics modules. Sponsor: Air Force. Industry developer: Perkin-Elmer.

3. *Systems:*

   a. *Coherent Laser Communication System* — The coherent laser communication technology developed for space applications can be used in ground fiber networks. The technology has been transferred to domestic telecommunications companies. Sponsor: Air Force. Industry developers: AT&T, GTE.

3.1.3 Space Surveillance

Technology

1. *Radar Imaging Analysis:* Techniques for wideband radar imaging for satellite identification and status monitoring are being transferred to the Air Force for application in a new space surveillance radar. User agencies: Air Force Space Command, and Foreign Technology Division of Systems Command.

Techniques

1. *Electro-Optical Sensing:* Lincoln Laboratory made modifications and developed new designs to improve the GEODSS (Ground-Based Electro-Optical Deep-Space Surveillance System) performance. The upgrades, which will be used at all GEODSS sites for implementation into the software operating systems, were transferred to the Air Force Space Command and Kentron. User agency: Air Force Space Command. Industry developer: Kentron.

2. *Coherent Integration:* Real-time coherent integration was implemented at the Millstone Hill radar to detect and track satellites at and beyond geosynchronous altitude (36,000 km). Coherent integration has permitted an increase in the radar's single pulse sensitivity by a factor of 10,000, corresponding to a tenfold increase in range. The technology was transferred to the ALTAIR radar, the FPS-79 radar, and the FPS-85 phased array radar. As a result, a global capability for tracking satellites in the geosynchronous belt has been added to the SPACETRACK network. Sponsor: Air Force. Industry developers: GTE, GE.

3. *Phased Array Radar:* Lincoln Laboratory helped the Air Force improve the deep-space tracking capabilities of the FPS-85 phased array radar. Modifications to the FPS-85 receiver and transmitter element designs have enhanced radar sensitivity by 4 to 6 dB. User agency: Air Force Logistics Command.

4. *Orbit Determination:* Improved analytic techniques for orbit determination have been developed and applied to high altitude satellite orbit determination. Operating in real time at the Millstone Hill radar, these techniques have permitted the rapid recognition of satellite maneuvers and radar malfunctions, and have provided improved orbit element sets. They are being used at the Millstone Hill radar, ALTAIR, FPS-79, and the GTS/ETS (GEODSS Test System/Experimental Test System) optical site at Socorro, NM. Sponsor: Air Force. Industry developers: GE, GTE.

5. *Training Courses on Use of Surveillance Resources:* Several groups of analysts and operators from the SPADOC (Space Defense Operations Center) and the SSC (Space Surveillance Center) attended training courses at the Millstone Hill radar facilities. The courses concentrated on high altitude surveillance with emphasis on the use of the radar and GEODSS resources for critical and routine missions. They have made SSC analysts proficient in the use of satellite surveillance resources. User agency: U.S. Space Command/Space Surveillance Center.

6. *GEODSS Search Techniques:* Optimal techniques for the search of high-altitude space satellites were transferred to Kentron and are routinely and regularly being applied at the sites. The command and control technology for integrating search and analysis has been made available to the U.S. Space Command. User agency: U.S. Space Command. Industry developer: Kentron.

7. *DPCA (Displaced Phase Center Antenna):* Lincoln Laboratory designed, fabricated, and tested an L-band, airborne array antenna operating in the displaced phase center mode. The novel feature of the antenna is the realization of extremely tight tolerances for the antenna components. Errors of 0.34° rms in phase and 0.10 dB rms in amplitude were achieved. In the 1980s the DPCA technique for canceling mainbeam radar clutter was improved for space radar applications and has become the technique of choice for most space-borne radar designs. Sponsor: Air Force. Industry developers: Raytheon, GE, Martin Marietta.

8. *INTACS (Integrated Network Tasking and Control Systems):* INTACS is a prototype system for integrating near-earth and deep-space nonhistoric NFL (New Foreign Launch) processing. It also provides the framework required to incorporate new space-based surveillance sensors as they become available. INTACS algorithms will be incorporated into a future version of the SPADOC (Space Defense Operations Center) system, or as a stand-alone operational system to SPADOC. User agency: Air Force Space Surveillance Center.

Components

1. *SBV (Space-Based Visible) Surveillance:* A visible wavelength optical sensor being developed for placement on the MSX satellite will demonstrate above-the-horizon surveillance capability from a space platform. The target and background phenomenology database will aid industry in understanding target detection and discrimination issues. The associated ground SBV Control Center will be transferred to the Air Force Space Command to prove the concept for command, control, and integration of space-borne sensors into the space surveillance network system. Sponsor: Air Force. User agency: Air Force Space Command.

2. *PACS (Processing and Control System):* The Haystack Processing and Control System's functions extend from digitizing receiver signals to recording data. Intermediate functions include pulse compression, tracking, real-time imaging, and control. The system was constructed using commercially available equipment, and is modular to allow software reconfiguration of the system to meet changing radar needs. The system is a candidate for the Deep-Space Surveillance Radar. Sponsor: Air Force Electronic Systems Division.

3. *Detection Signal Processor:* Detection signal processor technology is being transferred for use in high search rate electro-optical sensors for space surveillance applications. The technology transfer also includes computer codes and algorithms for the SSTS (Space Surveillance and Tracking System) on-board processors. User agency: Air Force Space Systems Division. Industry developer: TRW.

4. *LRIR (Long Range Imaging Radar):* This radar produces two-dimensional images of earth satellites by processing highly stable, coherent signals to extract target return range and Doppler information. Sponsor: Air Force.

5. *DSNCP (Deep-Space Network Control Processor):* The DSNCP program automates the processing of deep-space nonhistoric NFLs and includes algorithms and policies for efficient tasking of the deep-space sensor network. The DSNCP software was installed on the CASPADS (Computer Assisted Space Analysis and Data Systems) computer system at NORAD (North America Air Defense Command) Cheyenne Mountain Center. Several of the program's features were incorporated into the 427M tasking processor at NORAD. User agency: U.S. Space Command/Space Surveillance Center.

6. *ISD (Interactive Scenario Designer):* ISD provides system operators with an easy-to-use capability for postulating new launch scenarios. It was installed on the CASPADS computer at the CMAFS (Cheyenne Mountain Air Force Station) and has proven to be a valuable interactive tool for processing nonhistoric launches. User agency: U.S. Space Command/Space Surveillance Center.

7. *UCTP (Uncorrelated Target Processor):* The UCTP addresses the problems caused by the large numbers of uncorrelated target observations generated daily by the Space Surveillance Network. The UCTP correlates uncorrelated target observations with RSO (Resident Space Object) element sets, and augments the space object catalog with newly found satellites. UCTP technology will be utilized in the ASSOP (Advanced Surveillance System Observation Processor), which will be transferred to an Air Force contractor for integration into the Space Surveillance Network. User agency: U.S. Space Command.

Systems

1. *GEODSS (Ground-Based Electro-Optical Deep-Space Surveillance System):* Lincoln Laboratory has developed the concept of using highly sensitive detectors, agile telescopes, and automated signal processors to allow semiautomatic detection of satellites at 36,000 km and beyond. The concept was tested and transferred to the Air Force. Sponsor/User: Air Force.

3.1.4 Surface and Air Surveillance

Technology

1. *Ultra-Low Sidelobe Antenna:* Lincoln Laboratory, working jointly with Westinghouse, developed an antenna that has extremely low azimuth sidelobes. To achieve the low sidelobes it was necessary to identify, analyze, and quantify all potential sources of error in an antenna design and to develop techniques that minimize the effects of the sources of errors. User agency: Navy. Industry developer: Westinghouse.

2. *Cascaded Adaptive Array:* Lincoln Laboratory developed an adaptive array architecture that overcomes the problem of slow adaptive array convergence. The cascaded adaptive array uses a two-layered cascaded configuration which successively nulls first the large and then the small interferers. This successive processing allows for more rapid nulling compared with a single stage of processing. A patent application is in progress for the technology. Sponsor: Navy.

3. *MASR (Multiple Antenna Surveillance Radar):* MASR is an airborne MTI (Moving Target Indicator) radar that employs special antenna and signal-processing techniques to provide continuous, long-range, wide-area surveillance of moving targets on or near the ground. The program demonstrated stand-off detection of slowly moving targets and automated detection of convoys of armored vehicles, trucks, etc. L-band MASR technology is currently an important element in Space-Based Radar Technology. The Raytheon space radar concept also makes direct use of this Lincoln Laboratory-demonstrated technology. Sponsor: Air Force. Industry developers: Raytheon, Grumman.

Techniques

1. *Waveform Generator:* Lincoln Laboratory engineers demonstrated to Hewlett-Packard how one of their commercial products can be used as a specialized waveform generator for a high resolution radar application. Sponsor: Air Force. Industry developer: Hewlett-Packard.

2. *Adaptive Nulling Concepts:* Lincoln Laboratory developed digital adaptive nulling concepts that achieve low elevation sidelobes for the RST (Radar Surveillance Technology) Radar. The key to the technology was careful determination and quantification of the contributing sources of error. For example, it became apparent that channel equalization of the independent analog sources of data from the array elements was essential to achieving the requisite null depths. The technology was published and was discussed with Westinghouse, Raytheon, Hughes, and others. The Laboratory has also developed digital techniques which allow even further compensation for system errors. One such technique is diagonal loading which has been applied to RST processing. This technique was described in an IEEE paper. Sponsor: Navy. Industry developers: Raytheon, Westinghouse, Hughes.

3. *Adaptive Nulling Architecture:* Lincoln Laboratory invented a unique adaptive nulling architecture for sidelobe jammer and clutter suppression which features adaptive feedback coupled with the standard feed-forward approach. It results in very high levels of suppression, has been successfully tested, and is generally considered to represent the best way of eliminating jammer and clutter interference. Sponsor: Air Force. Industry developers: Raytheon, GE.

4. *Focused Near-Field Testing:* Lincoln Laboratory developed the concept of focused near-field testing of large adaptive radar antennas for pattern fidelity, jammer nulling, and clutter cancellation. This technique is highly accurate, makes use of the components already in the antenna system, and requires only an anechoic chamber of reasonable dimensions. Without this technique, full testing using conventional far-field techniques would be unreliable at best and in many cases impossible. Sponsor: Air Force. Industry developers: Raytheon, GE.

5. *Signal Processing Architecture:* The real-time signal processing in the Radar Surveillance Technology program contains important architectual contributions. Specific creative architectural design innovations by Lincoln which have been discussed extensively with industry involve the areas of detection, equalization, and beamforming. Mismatch errors in a synchronous detector cause degraded nulling performance. Two approaches developed at Lincoln Laboratory have addressed this problem; one has led to a custom integrated circuit, and the second uses high performance commercially available components. Both approaches have been discussed extensively with industry, including Westinghouse and XonTech. A second portion of the processor involves advanced architectural considerations and the efficient use of state-of-the-art technology to implement channel equalization. This processing has been discussed extensively with industry (e.g., Westinghouse) in conjunction with adaptive beam forming and analog-to-digital conversion. The latter led to a Lincoln-developed specification of A/Ds and a fabrication contract issued to Westinghouse. Digital adaptive beam forming applies some relatively complex mathematics and has led to a design of a systolic array which performs computations efficiently while minimizing I/O overhead. This application and the implicit architecture have been discussed extensively with the radar industry (Westinghouse, Raytheon, Hughes, and several others) and the computer industry (DEC and Motorola). Sponsor: Navy. Industry developers: XonTech, Westinghouse, Raytheon, Hughes, DEC, Motorola.

6. *SMI (Sample Matrix Inversion) Convergence:* The sample matrix inversion algorithm offers rapid convergence to an optimal solution. Lincoln Laboratory developed an analysis that examines the rate of SMI convergence under two criteria of goodness when the diagonal loading level is varied. This

analysis which has many adaptive nulling applications has been described in a technical paper accepted by IEEE for publication. Sponsor: Navy.

7. *Adaptive Sidelobe Blanker:* Lincoln Laboratory devised a method, using multiple steering vectors, that allows the use of both adaptive nulling and sidelobe blanking in a phased array antenna. A patent application is in progress. Sponsor: Navy.

8. *Multi-frequency Low-Angle Clutter Model:* As a result of a large clutter measurement program, Lincoln Laboratory developed a multi-frequency low-angle ground clutter model. The model is empirical, derived from dual-polarization measurements taken at VHF, UHF, L-, S-, and X-band at varied terrain types and depression angles, and is based on Weibull statistics. It is being used for clutter modeling and air vehicle survivability analysis at both contractors and defense facilities. Sponsor/User agencies: Air Force, Army, Navy.

9. *Terrain Specific Radar Propagation Model:* SEKE (Spherical Earth with Knife-Edges) is a software package that calculates radar power at distance (R) from the radar and an altitude (h) from the ground normalized to the free space power at that range R. Inputs to the program include digital terrain elevation data for the propagation path, R, h, radar antenna height, frequency, reflection coefficient, dielectric constant, and conductivity of the ground. SEKE can be run with or without a free space antenna pattern. Thirty-nine copies of the model are in use in the government and industry; the model is available from the MIT Technology Licensing Office. Sponsor: Air Force. Users: Government and industry.

10. *Superresolution Program:* Superresolution technology was developed at Lincoln Laboratory to permit direction finding and copy functions to be performed in the presence of interference in the HF, VHF, and UHF frequency bands. Data collected via the Laboratory's Airborne System are disseminated to several contractors. Industry users: Argo Systems, Hazeltine, E-Systems, Sanders, ITT, AIL Systems, AST.

11. *ADC (Analog-to-Digital Converter) Test-Bed:* Lincoln Laboratory developed the ADC test-bed to measure performance differences among available industry ADCs and to stimulate production of more capable units. The ADC Program has had a significant impact on industry. For example, Elsin used results of the tests to develop a 14-bit 5-MHz device and Westinghouse used test results to improve the performance of a prototype device. Both the Elsin and Westinghouse devices are being used in SIGINT (Signal Intelligence Technology) and radar systems. Tektronix, Analogic, and Analog Devices have adopted the SFDR (Spurious Free Dynamic Range) characterization technique and now list this parameter on data sheets. Tektronix is marketing a test instrument that performs many of the tests developed under this program. Sponsor: Air Force. Industry developers: TRW, Westinghouse, Elsin, Tektronix, Analogic, Analog Devices.

12. *Classification Algorithms:* Lincoln Laboratory developed classification algorithms and gathered data on tanks, trucks, and helicopters using an airborne radar. This information has been transferred via Harry Diamond Laboratory to Teledyne Systems to confirm performance numbers, and to Grumman for use in JSTARS (Joint Stand-Off Target Acquisition Radar System) development. Industry users: Teledyne Systems, Grumman, Lockheed.

13. *Air Surveillance:* Lincoln Laboratory is exploring the detection and recognition of airborne targets using IR imagery taken with the IRMS (Infrared Measurement System) sensor. Imagery data and algorithms developed by Lincoln Laboratory have been supplied to industry. Sponsor:Air Force. User agency: SAIC. Industry developers: Spectral Sciences, Georgia Institute of Technology, Martin Marietta.

Components

1. *Advanced Signal Processor:* Lincoln Laboratory built nine first-generation compact programmable signal/data processors. In FY 87, five of these processors were used in ground-based surveillance radars. Two radars were built for the ETAS (Elevated Target Acquisition System) mast-mounted sensor suite. To support these ground radars, Lincoln Laboratory transitioned hardware information, debugging knowledge, and real-time software to AIL/Eaton personnel. Sponsors: DARPA and Harry Diamond Laboratory. Industry developers: AIL/Eaton, Emerson.

2. *PMP (Parallel Microprogramming Processor):* Lincoln Laboratory developed a real-time radar signal digital processor, the PMP. It is a programmable processor designed to implement typical radar range gate algorithms. The PMP consists of a single control unit and an array of identical processing modules. The control unit sequences through a program stored in its control memory, providing identical instructions to each processing module so that all modules are performing the same operation in parallel, each on its own set of data. Sponsor: Air Force. User agencies: FAA, DARPA, Army, Sandia National Laboratory.

3. *Advanced Airborne Radar:* Lincoln Laboratory developed an advanced airborne radar that served as an experimental test-bed for developing advanced ground surveillance technology. This all-weather radar could be used in a small lightweight RPV (Remotely Piloted Vehicle) as a stand-off radar operating behind the forward edge of the battle area, or operating as a stand-off radar on conventional reconnaissance aircraft. Sponsor: Air Force.

4. *FERM (Finite Element Radiation Model):* In conjunction with the Superresolution Program, Lincoln Laboratory developed a computer program for electromagnetic modeling that computes antenna patterns and radar cross sections. The computer code and documentation have been distributed to more than thirty DOD and industrial concerns. Sponsor: Air Force. User agencies: DOD and defense industries.

5. *UAV (Unmanned Aerial Vehicle) Signal Processor:* Lincoln Laboratory developed both a first- and second-generation processor to provide a lightweight (54 lb) programmable, high-capacity (300-MOPS) signal processor for airborne use. The second-generation processor has potential application to the JSTARS system. Sponsor: Harry Diamond Laboratory. Industry developer: AIL/Eaton.

6. *Binary Optics:* Lincoln Laboratory's expertise in the use of binary optics has been transferred to several industries for a variety of applications. Examples of technologies transferred to industry include:

   a. The Laboratory fabricated an experimental star tracker optical assembly and surveyed Perkin-Elmer's IR tactical systems to evaluate the applicability and cost benefits of using binary optics. The use of binary optics halved the number of elements required in the star tracker system and improved performance. By applying binary optics, the cost for an IR

missile warning system can be reduced by approximately one-third and can provide better performance. Sponsor: DARPA. Industry developer: Perkin-Elmer.

b. Lincoln Laboratory assisted Honeywell in training their personnel in binary optics, and helped with the design and fabrication of high-speed germanium FLIR (Forward Looking Infrared) optics and focal plane microoptics for the DARPA/Army uncooled rifle-sight FLIR system. Microoptics have doubled the performance of FLIR, and the fore optics fabricated by Lincoln Laboratory eliminated two of the three optical elements, halved the optics costs, saved weight, and improved performance. Sponsor: DARPA. Industry developer: Honeywell.

c. As directed by DARPA, Lincoln Laboratory trained the NVL (Night Vision Laboratory) personnel in the design and fabrication of binary optics. Nearly every electrooptical system in NVL's design and procurement phase will be examined for cost benefits utilizing binary optics technology. Lincoln Laboratory is assisting NVL develop its own binary optics design, fabrication, and test capability. Sponsor: DARPA. User agency: Army Night Vision Laboratory.

d. The technology transfer of binary optics to Hughes covered many applications including AAWS-M (Advanced Antiarmor Weapon System-Medium) missile seeker designs, focal plane microoptics in cadmium telluride for the SDIO's LATS (Longwave Infrared Advanced Technology Seeker) program, and the use of anamorphic optics and dual field-of-view optics in APGMs (Advanced Precision Guided Munitions) designs for DARPA. In each case, technology transfer required training at Lincoln and fabrication of samples. Sponsors: DARPA, SDIO, and Army/SDC. Industry developer: Hughes.

e. The binary optics technology transfer to Rockwell also covered many applications and systems. Among these applications were nuclear hardened IR focal planes requiring microoptics for the SDIO LATS program, amacronic focal plane processing for Air Force missile seekers, diffractive antireflective coatings for Air Force instrumentation panels, and aberration corrected lens design for the Air Force Weapons Laboratory. Sponsor/User agencies: SDIO and AFWL. Industry developer: Rockwell.

f. Lincoln Laboratory transferred binary optics design techniques and fabrication technology to Polaroid, who used them to improve landscape lens technology in folded visible light camera systems. During the course of this program, Lincoln learned to mold and emboss binary optics master-elements in plastic materials, a technology that led to extremely low-cost FLIR optics. Sponsor: DARPA. Industry developer: Polaroid.

3.1.5 Air Traffic Control

Techniques

1. *Multipath Modeling Tools:* Lincoln Laboratory developed multipath modeling tools to aid in the development and evaluation of competing techniques for MLS (Microwave Landing Systems). The

tools were distributed to industry and were also used by Lincoln Laboratory to evaluate techniques proposed by industry for a major FAA acquisition. Sponsor/User agencies: FAA, and other industries.

2. *Moving Target Detector:* The Laboratory pioneered efforts to employ modern digital signal and data processing technology to improve the performance of ground-based radars operating in a wide range of clutter due to rain, birds, ground, etc. The signal processor, a parallel microprogrammed processor, was developed. The signal and data processing algorithms were incorporated in the ASR-9 (Airborne Surveillance Radar). Other programs have used this signal processor, e.g., the Netted Radar Program, the Advanced Ground Surveillance Radar, and the Multiple Antenna Surveillance Radar. Sponsor: FAA. Industry developers: Westinghouse, Stein Associates.

3. *TDWR (Terminal Doppler Weather Radar):* The TDWR system uses automatic computer algorithms for the detection of hazardous weather conditions. It detects and warns aviation users about low-altitude wind-shear hazards caused by microbursts and gust fronts. During a test of the TDWR at Denver's Stapleton International Airport in the summer of 1988, the C-band Doppler radar detected 47 microbursts within 5 mi of the airport and more than 200 microbursts within the entire area of coverage. TDWR will be installed at 47 sites around the country. This radar has been characterized as a major step forward in the detection of severe weather conditions at airport terminals. Sponsor: FAA. Industry developer: Raytheon.

4. *NEXRAD (Next-Generation Weather Radar):* The NEXRAD system uses an S-band (2.7 to 3.0 GHz) Doppler weather radar to collect reflectivity data, radial velocities, and spectrum widths of precipitation particles to detect and monitor large severe storms. The high accuracy reflectivity information is collected out to 290 mi, and Doppler information on mean radial velocity and spectrum width out to 145 mi. NEXRAD analyzes the information provided by the Doppler radar and generates automatic alerts directing the operator's attention to areas of potential hazard. UNISYS has been contracted to build ten of these systems. There are options to build 185 additional systems. Sponsor/User agencies: FAA, Air Force, National Weather Service, Naval Oceanography Command, Commerce Department-National Oceanic and Atmospheric Administration. Industry developer: UNISYS.

5. *Lincoln MLS (Microwave Landing System):* Under this FAA program Lincoln Laboratory developed a propagation simulation model that can be used to site MLS ground equipment and to determine the areas that should be clear of aircraft, vehicles, etc., so that the integrity of the information is maintained. The software and computer code of this system were transferred to the FAA, United Kingdom, and the Federal Republic of Germany. Sponsor: FAA. User agencies: FAA, Federal Republic of Germany, United Kingdom.

Systems

1. *Mode S (Mode Select) Beacon System:* Mode S (a combined beacon radar and ground-air-ground data-link system) is designed for dense traffic environments. It provides enhanced surveillance performance through monopulse, discrete addressing, and error protection. The Mode S will be purchased for all of the civilian beacon radar sites in the U.S. Sponsor: FAA. Industry developers: Westinghouse, Burroughs.

2. *TCAS (Traffic Alert and Collision Avoidance System):* TCAS was developed to reduce the possibility of midair collisions. This airborne system senses the presence of nearby aircraft by interrogating the transponders carried by these aircraft. When TCAS senses that a nearby aircraft is a possible collision threat, TCAS issues a traffic advisory to the pilot, indicating the presence and location of the other aircraft. If the encounter becomes hazardous, TCAS issues a maneuver advisory. In 1988 Congress passed a law requiring the installation of TCAS II equipment in all commercial aircraft in the U.S. by 1992. Sponsor: FAA. Industry developers: Honeywell, Collins, Bendix.

3.1.6 Advanced Electronics Technology: Solid State

1. *Techniques:*

   a. *Acceptor Doping of HgCdTe (Mercury Cadmium Telluride)* — Between 1987 and 1989, Lincoln Laboratory developed a technology for efficient acceptor doping of HgCdTe epitaxial layers. This technology is being used to dope HgCdTe wafers used in infrared focal planes. Sponsor: Air Force. Industry developer: Raytheon.

   b. *Tri-Arc Method* — Lincoln Laboratory developed a tri-arc method for crystal growth from a melt. The technology is under development by industry for growing very large single crystals of Ti:Al alloys for turbine blades. Sponsor: Air Force. Industry developer: GE.

   c. *Laser Photodeposition* — Lincoln Laboratory has obtained patents for laser photodeposition which a licensee has used to develop a machine for the repair of flat-panel displays. Sponsor: Air Force. Industry developer: Micron Technology.

   d. *Excimer Laser Lithographic Stepper* — A 193-nm excimer laser lithographic stepper which is under development will result in a high performance microlithographic stepper. The stepper is expected to have a major impact on the semiconductor industry. Sponsor: DARPA. Industry developer: Perkin-Elmer.

   e. *Laser Direct Write Technology* — Laser direct write technology developed by Lincoln Laboratory was transferred to industry for possible use in quick-turnaround gate arrays. Sponsor: Air Force. Industry developer: Gould/AMI.

   f. *Large Crossbar Switch* — Electron-beam-programmed floating gate techniques developed by the Laboratory were used to develop a large crossbar switch. Sponsor: Air Force. Industry developer: GTE.

   g. *Diamond Etching Technique* — A diamond etching technique developed at Lincoln has been applied in the development of backward-wave oscillators. This diamond etching technique has been patented and is being used by industry. Sponsor/User agency: NASA.

   h. *Diode Laser Arrays* — Lincoln Laboratory was the first to demonstrate a technology for achieving high power monolithic two-dimensional arrays of surface emitting diode lasers. The technology employs etched laser facets and a deflection mirror integrated in each laser in a large array. Sponsor: Air Force. Industry developer: TRW.

i. *Analog Fiber Optic Links* — Technology for achieving high linearity and dynamic range in analog optical links removes one of the main obstacles that has limited the use of fibers for RF and microwave signal transmission. There may be applications of this technology in DARPA's space-based radar. There are large potential commercial applications of the technology for telephone and video networks. Discussions are taking place with Fairchild and Raynet. Sponsor: Air Force.

j. *Battery Material Processing* — Under the Re-entry Systems Program, Lincoln Laboratory developed processes to remove unwanted hydrogen from high energy density, lithium-thionyl chloride batteries. A high temperature process was developed to treat separator paper in order to remove residual hydrogen while maintaining strength and electrical insulative properties. A drying technique to remove residual water vapor and a residual hydrogen measurement technique were also developed and demonstrated. Sponsor: Air Force. Industry developer: Battery Engineering.

k. *X-Ray Lithography* — X-ray lithography for microelectronic fabrication was invented and demonstrated at Lincoln Laboratory in the early 1970s and has now become an important part of the DOD VHSIC (Very High Speed Integrated Circuit) program. Sponsor: Air Force. Industry developers: IBM, AT&T, Perkin-Elmer, Hampshire Instruments, Spire Corp.

l. *Proton Isolation of GaAs (Gallium Arsenide) Devices* — In the early 1970s Lincoln Laboratory demonstrated the use of proton bombardment to electrically isolate GaAs microwave devices. The process is now an important fabrication step for many commercial GaAs microwave devices. Sponsor: Air Force.

m. *Low Temperature GaAs* — An insulating GaAs layer, developed at Lincoln Laboratory, completely eliminates sidegating of GaAs transistors from adjacent devices and thereby facilitates a higher packing density of devices on GaAs integrated circuits. Sponsor: Air Force. Industry developers: Hewlett-Packard, GE, Motorola, Celeritek.

n. *Microchannel Heat Sinks* — Lincoln Laboratory developed microchannel heat sinks by using silicon and other materials to extract heat loads approaching 1 kW/cm^2 from high power devices, especially from two-dimensional diode laser arrays whose fundamental power density limit is imposed by heat sink capacity. This application resulted in record-setting laser array performance. Patents covering microchannel design are pending, and software for performance prediction and design selection has been sold to several companies through the MIT Technology Licensing Office. Sponsor: AFWL. Industry developers: TRW, David Sarnoff Laboratories.

o. *Hydroplane Polisher* — In the late 1970s Lincoln Laboratory developed a noncontact polishing technology that saved the HgCdTe infrared detector industry and is now universally used. It has increased detector sensitivities by one order of magnitude. Sponsor: Air Force.

p. *Gas-Source MBE (Molecular Beam Epitaxy)* — Lincoln Laboratory was the first to develop and use gas sources for the MBE of III-V compounds. Most major laboratories now use gas-source MBE systems to grow highest quality materials such as GaAs. Sponsor: DARPA.

q. *Superconductor Resonator Technique* —The technology of packaging superconducting thin film devices as microwave-frequency resonators for material evaluation was developed at Lincoln Laboratory. Superconducting films have the potential of making higher performance microwave components, and it is important to characterize the materials in an actual device such as the resonator. Sponsors: Army, Air Force, DARPA. Industry developer: Superconducting Technologies.

2. *Components:*

a. *CCD (Charge-Coupled Device) Signal Processing Chip* — An integrated-circuit process that combines analog CCDs and digital transistor circuits has been used for the production of correlator chips. Sponsor: Air Force. Industry developers: Ford Aerospace, Stanford Telecommunications (under a NASA contract).

b. *CCD Fabrication Technology* — Lincoln Laboratory developed process and design technology for CCD signal processing chips. The design of Single-Level-Metal process technology for the Analog-Binary Correlator chip was transferred to Fairchild and to Ford Aerospace; the Double-Level-Metal process and design technology were transferred to Reticon; and the CCD Matrix Matrix Product signal processor device was transferred to Ford Aerospace. Industry developers: Fairchild, Ford Aerospace, Reticon.

c. *Focal Plane Arrays* — Lincoln Laboratory fabricated and tested monolithic focal plane arrays that integrate iridium silicide Schottky-barrier detectors with CCD readout circuitry for long-wavelength infrared imaging. Sponsor: Air Force. Industry developer: Ford Aerospace.

d. *Broadband Faraday Isolator* — A broadband Faraday isolator has been built using an optically active rotator to compensate the dispersion of a 45° Faraday rotator. Its isolation is better than 30 dB from 735 to 870 nm. Over this wavelength range the measured transmission in forward direction is better than 80 percent. Sponsor: Navy. Industry developer: Isowave.

e. *Logic Device Integration* — Lincoln Laboratory pioneered the development of very compact low-power-consumption integrated circuits for radar applications. A first-generation integrated phase shifter/logic device fabricated on a single monolithic GaAs substrate was successfully developed. Industry developer: Hughes.

f. *LNA (Low Noise Amplifier)* — One of the critical components of solid state transmit/ receive modules and receivers for radar applications is the LNA which determines the system noise figure, dynamic range, and other parameters. The Laboratory promoted the development of low noise figure, high dynamic range, extremely small size monolithic

LNAs for a wide range of applications. Versions of this technology are now available in the marketplace. Industry developer: Adams Russell.

g. *GaAs Monolithic Attenuators* — Lincoln Laboratory worked with GE to develop miniature-size GaAs monolithic attenuators for amplitude control of RF signals in radar receivers that use segmented dual-gate field effect transistors. These GaAs monolithic attenuators offer high precision, multiple-level settings, low phase shift, and low power consumption. Sponsors: Air Force. Industry developer: GE.

h. *RF Switch Devices* — Working with Adams Russell, Lincoln Laboratory developed reliable, operating monolithic switches using field effect transistors. These switches are now commercially available. Sponsor: Air Force. Industry developer: Adams Russell.

i. *GaInAsP (Gallium Indium Arsenide Phosphide) Diode Lasers* — Lincoln Laboratory pioneered the development of quaternary lasers that are used in all military systems operating in the 1.3- to 1.5-μm bands. Lasertron, a company founded by Lincoln Laboratory employees, is the largest independent U.S. supplier of quaternary diode lasers. Sponsor: Air Force. Industry developers: Lasertron, AT&T.

j. *Graphite-Epoxy Sandwich Mirrors* — The first graphite-epoxy mirror suitable for optical use was developed at Lincoln. This mirror offers significant advantages in mass, stiffness, thermal properties, and manufacturing costs. Patents are pending on the graphite-epoxy mirror design. Sponsor: Navy. Industry developer: Composite Optics.

k. *Lightweight Graphite-Epoxy Tubes* — A new fabrication process produces lightweight aluminum-clad graphite-epoxy tubes. These tubes, which are stiff, lightweight, and have low thermal expansion, were originally designed to provide truss elements for large mirror structures in space. A patent is pending. Sponsor: Navy. Industry developer: ALCOA.

l. *Semiconductor Lasers* — Lincoln Laboratory was one of three laboratories to develop the first semiconductor laser. The technology is used in a large number of military and commercial products. Sponsors: Air Force and NSF.

m. *Co_2 Laser Technology* — Lincoln Laboratory developed an ultrastable, sealed-off gas laser that optimized operating parameters. Sponsor/User agency: Air Force. Industry developer: Apollo Lasers.

n. *$Co:MgF_2$ (Cobalt Magnesium Fluoride) Laser* — An efficient broadly tunable laser system operating in the 1.6- to 2.4-μm region was developed by the Laboratory. Sponsor: Air Force. Industry developer: Schwartz Electro-Optics.

o. *$Ti:Al_2O_3$ (Titanium Aluminum Oxide) Laser* — Lincoln Laboratory developed a $Ti:Al_2O_3$ tunable laser system for the 0.6- to 1.0-μm region. An annealing technique for reducing parasitic infrared absorption of $Ti:Al_2O_3$ crystals was also developed by the Laboratory and transferred to industry. Sponsor: Navy. Industry developers: Schwartz Electro-Optics, Union Carbide, Spectra-Physics, Excel Technology.

p. *SAW (Surface Acoustic Wave) Devices* — The Laboratory developed SAW grating devices for signal processing and for improving signal enhancement over noise. SAW grating devices are used in communications systems, cable television, and color television. Sponsor: Air Force.

q. *Diamond Transistors* — Lincoln Laboratory has a patent pending on fabrication techniques for diamond transistors that can function at 500°C. Sponsor: Office of Naval Research. Industry developer: Diamond Materials.

r. *Integrated Optical Waveguide Devices* — $LiNbO_3$ integrated optical waveguide devices were developed by the Laboratory. High-speed modulators for fiber-optic communication systems and optical couplers for fiber-optic gyroscopes have been incorporated into military equipment. Sponsors: Air Force and NSF. Industry developer: Crystal Technology which markets a complete line of integrated optic devices.

s. *SAW Chirp Filter* — Lincoln Laboratory developed SAW components which provide wide bandwidth filtering capability for pulse compression and Doppler analysis in radar systems, and for adaptive filtering and signal demodulation in communications systems. It has been successfully used in the FLEETSAT EHF Package on Navy communications satellites. Sponsors: Air Force and Navy. Industry developers: Texas Instruments, Hughes, TRW.

t. *SAW/FET (Surface Acoustic Wave/Field Effect Transistor)* — This device, which can simulate the very long electrical delays associated with the plume of a re-entering missile, was used in the Active Decoy Phase II program. Sponsor/User agency: Air Force.

u. *Gallium Arsenide PBTs (Permeable-Based Transistors)* — Lincoln Laboratory conceived of and developed Gallium Arsenide PBTs for integration into monolithic microwave and digital circuits. Sponsor: Air Force. Industry collaborator: M/A-Com Linkabit.

v. *Resonant Tunneling Devices* — In 1983 Lincoln Laboratory demonstrated that resonant tunneling diodes could respond at frequencies as high as 2500 GHz. Numerous devices that use this technology have been demonstrated, including oscillators with up to 425 GHz. Two patents are currently held in this area, and several companies have exploited resonant tunneling concepts in experimental devices and circuits. Industry developers: Hughes, AT&T, Texas Instruments.

w. *Corner-Cube GaAs Mixer Diode* — A Schottky-barrier GaAs diode incorporating a novel corner-cube reflector as an impedance matching antenna was developed by Lincoln Laboratory for use as a mixer in submillimeter-wave heterodyne radiometers. These devices improved the sensitivity of these receivers by a factor of ten and had a substantial impact in radio astronomy, plasma diagnostics for fusion reactors, and in high-altitude rocket plume detection technology. Sponsors: DOE and Army. Industry user: Millitech.

3. *Systems:*

   a. *CCD Imager Technology* — Charge-coupled device imagers have been developed by the Laboratory that provide high quantum efficiency over a broad spectral range and with a very low readout noise. This technology is being used in a visible sensor for the BSTS (Boost Surveillance and Tracking System) Program and the SSTS (Space Surveillance Tracking System) Program. TRW is using the Lincoln CCD Imager for their VUE-II (Visible Ultraviolet Experiment-II). Lincoln Laboratory also has developed CCD cameras. Designs, performance data, and the thinned imager technology have been shared with several companies interested in utilizing this technology. Sponsor: Air Force. Industry developers: Rockwell, Hughes, TRW, SAIC, Kodak.

   b. *External Cavity Diode Lasers* — External cavity diode lasers have been developed that operate at linewidths below 4 kHz. These lasers are ideally suited to offset frequency locked operation in applications including coherent communications. Sponsor: AFWL. Industry developers: McDonnell Douglas, AT&T.

   c. *Long Pulse Lamp Pumped Nd:YAG (Neodymium Yttrium Aluminum Garnet) Lasers* — The Laboratory developed diffraction-limited, smooth pulse, high energy lasers operating at 1.06 and 1.3 μm. Sponsors: Air Force and NSF. Industry developer: Quantel International.

3.1.7 Advanced Electronics Technology: Computers

1. *Techniques:*

   a. *Multidomain Target Recognition* — Lincoln Laboratory has been selected by DARPA to work with industry to evaluate the usefulness of neural networks versus classical Automatic Target Recognition techniques. The Laboratory is providing to the contractors a multidomain database from the IRAR (Infrared Airborne Radar) ground and airborne sensors and is processing the database on a Lincoln-developed model-based target recognition system as a comparative baseline. Sponsor: DARPA.

   b. *SLASH (Standard Linking Automation Shell)* — This is a CAD (Computer Aided Design) tool developed by Lincoln Laboratory for laser restructuring of wafer-scale circuits. SLASH allows the user to determine the necessary redundancy of cells and tracks on wafer-scale layouts based on projected cell yields. Sponsors: Air Force and DARPA.

   c. *CCSIM (Call-by-Call Simulator)* — CCSIM was developed as a tool for modeling the emerging worldwide military telephone system called the DSN (Defense Switched Network). CCSIM supports experimental development of route selection algorithms to be used in the DSN. Network management techniques were developed using CCSIM to keep DSN operational in the presence of equipment and traffic disruptions. DCA is using it in its European Headquarters. Sponsor/User agency: Defense Communications Agency. Industry developer: GTE.

d. *Wideband Signal Detection and Direction Finding Algorithms* — In 1984 Lincoln Laboratory developed an algorithm to detect and determine directions of aircraft using microphone arrays. This algorithm was applied by Lawrence Livermore to seismic array processing. The same code was given to the Army Cold Regions Research Laboratory for research into tactical applications of seismic and acoustic arrays. Sponsor: DARPA. User agencies: Lawrence Livermore Laboratory, Army Cold Regions Research Laboratory.

2. *Components*:

a. *Wafer-Scale Technology* — Lincoln Laboratory has developed a monolithic wafer-scale digital integrated circuit technology which uses laser-based restructurable interconnect for defect avoidance and customization. The technology supports very high throughput rates for such signal processing applications as multiple jammer nulling. Sponsor: DARPA. Industry developer: Westinghouse.

b. *MUSE (Matrix Updating Systolic Experiment) Wafer* — This circuit is a monolithic wafer-scale adaptive nulling processor developed for space-based radar applications. Sponsor: Air Force. Industry developer: Westinghouse.

c. *Interface Boards* — Lincoln Laboratory specified, designed, and fabricated a set of interface boards that would provide high-speed data flow between processing elements. In particular, Lincoln Laboratory designed, and Star Technologies built, an interface between a high-speed direct memory access port on the ST-100 array processor and a Dataram bulk memory. A second interface, used to transfer radar signatures and images between the central memory (Dataram) and the general-purpose control and display computers, was also developed jointly by the Laboratory and Star Technologies. Sponsor: U.S. Army Strategic Defense Command. Industry developer: Star Technologies.

3. *Systems:*

a. *ETC (Expert Tech Controller)* — In 1988 Lincoln Laboratory developed an expert system to augment scarce and volatile Air Force communications technician skills. ETC has become a valuable teaching and demonstration tool. Sponsor/User agency: Air Force RADC/DC. Industry developer: Structured Software and Systems.

b. *Acoustic Tracking Algorithms* — Algorithms and software were developed by Lincoln Laboratory to perform real-time aircraft tracking using data from small ground-based microphone arrays. As part of a DARPA/Army study of the utility of acoustic sensors for tactical battlefield applications, the tracking software was transferred to SAIC and integrated into an overall air defense simulation model. Sponsors: DARPA and Army. Industry developer: SAIC.

c. *STC (Sinusoidal Transform Coder)* — In 1984, Lincoln Laboratory developed a new technique for speech analysis and synthesis based on modeling speech as a sum of sinewaves

with time-varying amplitudes, frequencies, and phases. This led to a high-performance voice coder applicable to secure voice systems which drew significant interest from industry, as well as the DOD and other government agencies. Early in 1989 a commercial secure voice terminal product was created with the STC algorithm. Sponsor: DARPA. User agency: VOA (Voice of America). Industry developer: CYLINK.

d. *Sinusoidal Analysis/Synthesis Speech Enhancement System* — This system was originally developed for RADC (Rome Air Development Center), and was then successfully extended to implement a speech enhancement processor that increased the effective range of Voice of America broadcasts. A prototype unit was delivered to VOA in March 1989. Sponsor/User agencies: RADC, VOA.

e. *Packet Voice Terminal* — In 1983-84 Lincoln Laboratory developed and tested terminals which would provide voice service over an existing packet network. Four advanced development models of the terminals were built and the technology was transferred to ACC (Advanced Computer Communications) which is developing user interfaces for the data network. ACC has developed these terminals and sold a number of them to the Navy. Sponsors: DARPA and Navy. Industry developer: ACC

f. *Compact LPC (Linear Predictive Coder)* — Lincoln Laboratory developed the first compact single board implementation of the government-standard LPC 2400-bps vocoder. This vocoder's design was based on one of the first commercially available microcomputer chips designed specifically for digital signal processing, the NEC 7720. The implementation of Lincoln Laboratory's compact vocoder was instrumental in initiating the STU-III (Secure Telephone Unit-III) low-cost secure voice terminal. The vocoder was subsequently redesigned by several contractors in their STU-III products. Sponsors: DARPA and NSA. Industry developers: Motorola, AT&T, RCA.

   The LPC was generalized into a computer-controllable Speech Processing Peripheral Unit. Sixty copies of the LPC were distributed to speech researchers in DOD organizations and have been used in a variety of research and development activities, including multimedia conferencing over packet networks. Sponsor: DARPA. User agency: DOD organizations.

g. *Wordspotting* — The Laboratory is developing a wordspotting system for automatic recognition of key words in continuous speech. The system is based on computation architecture consisting of multiple digital signal processors working in conjunction with a real-time workstation. Sponsor/User agency: NSA.

3.1.8 High Energy Laser Beam Control Technology

Techniques

1. *Laser Diagnostics:* Lincoln Laboratory developed a suite of instruments that evaluate high energy laser performance. Most of the instruments are one of a kind and were developed for use as laser diagnostics for beam jitter, beam quality, beam intensity patterns, and other characteristics. The design of

these instruments has been the model for other companies that are building similar diagnostic instrumentation. User agencies: Army-White Sands Missile Range High Energy Laser Facility and site contractor O&M.

2. *Diode Laser Monitoring and Spectroscopy:* Lincoln Laboratory developed monitoring and spectroscopic technologies including long path monitoring and FM/derivative spectroscopy. Sponsor: Air Force. User agencies/Industry developers: Laser Analytics, Los Alamos National Laboratory.

3. *Optical Chirp Compression:* Lincoln Laboratory developed the technique of using nonlinear optical self-phase modulation followed by dispersive delay to produce femtosecond pulses. This technology has been used by Spectra Physics in a commercial product and the technology is also being used by government laboratories. Sponsors: Air Force and DARPA. Industry developer/User agencies: Spectra-Physics, government laboratories.

4. *Beam Control Technology:* Subscale experimentation and component development are being performed by the Laboratory for the Free Electron Program. At the request of the Army/SDC, Lincoln has been transferring its knowledge of the operation of beam-control system to subcontractors. Sponsor/User agency: Army/SDC. Industry developer: Lockheed.

5. *Beam Path Conditioning Systems:* Lincoln Laboratory developed techniques for actively conditioning the beam path in high energy beam directors: boundary layer control on mirrors, thermal conditioning of beam expander cavities, thermal control of vacuum windows, and exit window configurations. Design concepts and performance analyses have been disseminated through papers and meetings. Sponsor: Army. Industry developers: Perkin-Elmer, JAYCOR.

6. *Control Theory Development:* A joint paper by Lincoln Laboratory and Harris Corporation's Government Aerospace Systems Division described advances in control theory that can handle parametric uncertainties and nonlinearities. Sponsor: Army. Industry developer: Harris.

Components

1. *Satellite Orbit Computations:* Lincoln Laboratory developed a software package for computing look angles and other information for satellite passes. Developed for the Firepond site, the program provides information on pass characteristics such as sun illumination, terminator mode conditions, metric information summary, etc. User agency: Army-White Sands Missile Range High Energy Laser Facility. Industry developers: Hughes, UNISYS.

2. *Deformable Mirror Driver Circuits:* Under the Army Beam Control Technology Program, Lincoln Laboratory provided electronic circuit schematics and printed-circuit-board art work to Lockheed. As the Beam Control System contractor for the Army's Ground-Based Free-Electron Laser Technology Integration Experiment, Lockheed will evaluate these deformable mirror actuator driver circuits. Sponsor: Army. Industry developer: Lockheed.

3. *Fast Steering Mirror Controls:* A state-of-the-art control system for a fast steering laser mirror was transferred to UTOS (United Technologies Optical Systems). Sponsor: Army. Industry developer: United Technologies Optical Systems Division.

Systems

1. *Auxiliary Beam Director:* Lincoln Laboratory built a 1-m-diameter clear aperture coelostat beam director for pointing instruments and laser beams at dynamic targets. This Auxiliary Beam Director was based on an existing optical mount augmented with computers, recorders, control systems, and trackers. The features were fashioned after Firepond, Haystack, and KREMS instruments and utilized techniques that had been found most effective over the years. Sponsors: Army and Air Force. User agency: Army-White Sands Missile Range. Industry developer: Dynaelectron.

3.2 EARLIER ACTIVITIES (1953-1969)

3.2.1 Strategic Offense and Defense

Techniques

1. *Re-entry Physics Program:* Initiated in 1958, research on phenomena such as the effects of ionization produced by a re-entering body on the electromagnetic scattering characteristics of the body led to the development of techniques for tracking and detecting re-entering ballistic missiles. Sponsor: ARPA.

Systems

1. *SAGE:* In the early 1950s Lincoln Laboratory developed the SAGE (Semi-Automatic Ground Environment) network, an integrated computer-based air defense system. SAGE was the basic component of the continental air defense program. Its purpose was to observe, record, calculate, and transmit information on hostile aircraft. In 1958 the operational implementation phase was transferred to MITRE. Sponsor: Air Force. Industry developers: IBM, Burroughs, Rand.

2. *DEW (Distant Early Warning) Line:* The DEW Line was a system of surveillance radars and communication links extending across the northernmost part of North America from Alaska to Greenland. It was designed to give early warning of aircraft approaching via polar routes. Sponsor: Air Force.

3. *BMEWS (Ballistic Missile Early Warning System):* BMEWS, the missile-age counterpart of the DEW Line, went into operation in 1957. Extensive studies were made of ballistic missile trajectories and problems of radar detection and tracking of missiles. The Millstone Hill radar was designed and built as a prototype for the BMEWS radars and a test-bed for many of the components and techniques of the system, including data processing and display equipment. The Millstone radar served as a model for similar large tracking and measurement radar systems installed at Prince Albert Radar Laboratory (Canada); Wallops Island, VA (for NASA); and an Air Force tracking station in Trinidad. Sponsor: Air Force. Users: NASA, Canada.

4. *AICBM (Anti-Intercontinental Ballistic Missile):* The AICBM program began at Lincoln Laboratory in 1953 and ended in 1960. It involved the design, development, and experimental testing of high-powered, long-range radar systems for the detection and parameter measurement of ICBMs, and to planning tests of a complete detection and prediction system against experimental missiles. In addition

there were requirements for computers matched to the special data processing functions involved, as well as studies of problems of detection and trajectory prediction. The program utilized the Millstone radar system and the transistorized CG-24 computer. Sponsor: Air Force.

5. *PRESS (Pacific Range Electromagnetic Signature Studies) Project:* In 1960 Lincoln Laboratory was designated Scientific Director for the PRESS Project. The early major sensor and data processing systems developed for this project were TRADEX (1962), and ALTAIR (1969). (See KREMS Project section on p. 8.) Sponsors: DARPA and Army. User agency: Sandia National Laboratory. Industry developers: TRW, XonTech, Ford Aerospace, Lockheed, GTE, Avco.

6. *AMRAD (ARPA Measurements Radar):* This L-band radar was designed and operated by Lincoln Laboratory in the 1960s. Installed at White Sands Missile Range, it was used for target designation and discrimination using radar-observable phenomena associated with ballistic missile flight. Sponsor: ARPA. User agency: Army-White Sands Missile Range.

3.2.2 Satellite Communications

Technology

1. *Project Mercury*: In 1959 NASA (formerly NACA) asked Lincoln Laboratory for technical assistance in the establishment of a worldwide ground-tracking and communications facility for Project Mercury, the first U.S. program for manned orbital flight. Sponsor/User agency: NASA. Industry developer: Western Electric.

Techniques

1. *WEST FORD:* Project WEST FORD tested a method for highly reliable, long-range radio communication by means of reflections from orbiting copper-wire dipoles. About 400-million hair-like copper fibers were placed in a narrow orbital belt around the earth. The experiment demonstrated that the orbital dipole scattering technique was sound and could serve as an economical and extremely reliable worldwide communications system for either military or civilian use. Sponsor: Air Force.

Systems

1. *LES (Lincoln Experimental Satellites):* For over 25 years, the Laboratory has been developing and demonstrating advanced system concepts and technologies for communications satellites. The LES program began in 1963 and led to the development of the LES-1 (February 1965), LES-2 (May 1965), LES-3 (December 1965), LES-4 (December 1965), LES-5 (July 1967), LES-6 (September 1968), and LES-8/9 (March 1976). The technology from these programs has been incorporated into the IDCSP (Initial Defense Communications Satellite Program). The first satellites were built by Ford Aerospace; satellites for the DSCS (Defense Satellite Communications System) were built by TRW and GE. Sponsor: Air Force. Industry developers: Ford Aerospace, TRW, GE.

3.2.3 Computer Systems

1. *Magnetic Core Memory:* In the early 1950s Lincoln Laboratory invented the magnetic core memory which was subsequently installed in Whirlwind. The magnetic core memory, consisting of an array of small, doughnut-shaped ferrite cores, was considered a building block for future high-speed digital computers. A patent was issued to MIT and licensed to major computer manufacturers. Sponsors: Navy and Air Force. Industry developers: IBM and other manufacturers.

2. *WHIRLWIND:* The first high-speed electronic, real-time, digital computer developed at Lincoln Laboratory used random-access magnetic core memory which is described above. The computer contributed significantly to computer technology. Sponsor/User agency: Office of Naval Research.

3. *AN/FSQ-7:* This computer was designed by Lincoln Laboratory, built by IBM, and installed in the SAGE System. The computer processed large quantities of information from many sources to identify and track aircraft. Sponsor: Air Force. Industry developer: IBM.

4. *TX-0:* The TX-0 computer, one of the first computers to use transistorized logic circuits, was designed as a general-purpose machine capable of functioning as a complete computing system. Designers of the TX-0 computer founded DEC (Digital Equipment Corporation). Sponsor: Air Force. Industry developer: DEC.

5. *TX-2:* This computer was conceived as the machine for full testing of the core memory and transistorized logic circuits. The incorporation of the multiple-sequence program technique made possible the simultaneous operation of several input/output devices, and resulted in a more efficient use of computer time. Sponsors: Air Force and DARPA.

6. *CG-24:* This computer was designed, built, and placed in operation at the Millstone Hill radar in 1958. In addition to demonstrating the value of automatic pointing and tracking of radar antennas, the CG-24 was a major factor in the development of real-time signal processing techniques which were essential to the evolution of modern space-tracking and measurement radars. Sponsor: Air Force.

7. *LINC (Lincoln Instrument Computer):* The forerunner of the personal computer of today, LINC was designed to be small and inexpensive for use in a laboratory environment. LINC, which was subsequently produced in a commercial version, was particularly useful in biomedical research. Sponsor: Air Force.

8. *LX-1:* This computer was built in 1969 as a prototype microprocessor to study the problems of designing a similar computer to be constructed with large-scale integrated circuits. LX-1 also demonstrated that microprogramming could be used for digital control and real-time digital encoding of speech. Sponsors: ARPA and Air Force.

9. *FDP (Fast Digital Processor):* Built in 1969-70, FDP was one of the first high performance general-purpose digital processors developed specifically to perform digital signal processing functions such as digital filtering and discrete Fourier transforms, at or near real time. The processor has been used in communications, radar, speech processing, biology, medicine, seismology, and sonar. Sponsor: ARPA.

3.3 TACTICAL TECHNOLOGY

Technology

1. *MTI (Moving Target Indicator) Radars:* In 1966 the Laboratory was asked to explore the problems of detecting moving targets through foliage. Camp Sentinel Radar was developed and used by the Army in Vietnam in 1968. Sponsor/User agency: Army.

Techniques

1. *ECCM (Electronic Counter-Countermeasures):* The vulnerability of radars to electronic countermeasures, principally jamming, led the Laboratory to develop several anti-jamming techniques. Some of the techniques included, cross-over which was used in SAGE, CFAR (Constant False Alarm Radar) detection, TACCAR (Time Averaged Clutter Coherent Airborne Radar), AMTI (Airborne Moving Target Indicator), and the NOMAC (Noise Modulation and Correlation) detection system. Sponsor: Air Force.

2. *Emitter Homing Program:* Lincoln Laboratory developed technology that supports lethal Command, Control, and Communications Countermeasures against low frequency transmitters including jammers and communication emitters. The Laboratory developed a computer code for a six-degree-of-freedom closed loop simulation. This technology was demonstrated via flight tests at Eglin AFB and the results were presented at a symposium and written in several reports to industry. Sponsor: Air Force.

Components

1. *CCD Matched Filter:* A CCD matched filter was developed under the JRSVC (Jam Resistant Secure Voice Communication) program. The technology was developed in conjunction with RCA, Ford Aerospace, and Fairchild and was transferred to several industries and the government for various applications. Sponsor: Air Force. Industry developers: RCA, Ford Aerospace, Fairchild.

3.4 MISCELLANEOUS TECHNOLOGY

1. *Photovoltaic/Thermal Collectors:* Lincoln Laboratory designed, constructed, and evaluated residential photovoltaic systems in collaboration with the Solar Energy Research Institute. Residential photovoltaic systems are in operation in New Mexico, Hawaii, Utah, and Massachusetts. Sponsor/User agencies: Department of Energy (DOE), Air Force, and Solar Energy Research Institute.

2. *Gallium Arsenide Solar Cells:* Research on GaAs solar cells demonstrated the feasibility of fabricating efficient, inexpensive thin-film solar cells for large-scale terrestrial applications. Sponsor/ User agency: Department of Energy (DOE).

3. *Seismic Discrimination:* In the 1960s a LASA (Large Aperture Seismic Array) was designed to detect underground nuclear explosions and distinguish them from natural seismic events of comparable magnitude. The array has a diameter of about 200 km, comprising 21 subarrays with 25 seismometers in

each array. LASA has been an extremely effective tool for advanced seismological research, leading to new insights into the interior structure of earthquakes. Sponsor/User agencies: ARPA, Nuclear Regulatory Commission, NSF.

4. *EASYPLOT:* An easy-to-use scientific plotting and data analysis package that runs on IBM personal computers, EASYPLOT accepts a wide range of input formats and allows the user to create sophisticated graphics, including 3-D surfaces. Industry developer: Spiral Software (licensee).

5. *Thermomagnetization Theory of Ferrimagnets:* Significant refinements to the molecular-field model of ferrimagnetism were developed at Lincoln Laboratory for the design of microwave ferrites. This model not only provides an accurate tool for predicting the critical magnetic properties of a wide variety of chemical compositions for tailoring to specific applications, but gave important new insights into the basic mechanisms of the magnetization process. The results of this work have subsequently also been adopted worldwide for the design of epitaxial films in bubble memory and magneto-optical applications. Sponsors: Army and ARPA.

6. *The VSM (Vibrating Sample Magnetometer):* A method for measuring the magnetic properties of vibrating specimens as a function of temperature through their interaction with an applied magnetic field was invented and perfected at Lincoln Laboratory. The VSM has become the most widely used instrument of its type, and is manufactured internationally by a variety of companies. Sponsor: Air Force. Industry developer: Princeton Applied Research.

7. *Synthesis of Lanthanum Copper Oxide for Superconductivity:* The original chemical synthesis and crystallographic characterization of La_2CuO_4 were carried out at Lincoln Laboratory. This composition was the host lattice used in the first high-T_c superconductors, and the Laboratory results published in the open literature served as the guide to the eventual discovery of the $La_{2-x}Sr_xCuO_4$ superconductor family by IBM in Zurich. Sponsor: Air Force.

4. TECHNOLOGY TRANSFER TABLE BY MISSION AREA

4.1 RECENT ACTIVITIES (1970-1989)

Mission	Technology/Product	Page Number	Sponsor; User Agency; Industry Developer
STRATEGIC OFFENSE AND DEFENSE		5	
Technology	ACTIVE REPLICATION OF RE-ENTRY VEHICLES	5	Air Force Ballistics Systems Division; GE
	TELEMETRY FROM A PLASMA EFFECTS DECOY	5	Air Force Ballistics Systems Division; Acurex
	PLASMA PREDICTION AND MEASUREMENT	5	Air Force; Air Force Ballistics Systems Division
	AEROSOL CONCEPT FOR OPTICAL INFRARED MASKING	5	Air Force
	FERRITE PHASE SHIFTERS FOR ARRAY RADARS	5	Army, DARPA; Raytheon, Trans-Tech., Ampex
	SUBMILLIMETER-WAVE RADIMETRY OF ROCKET PLUMES	6	Army; Millitech
Techniques	CARBON-LOADED TEFLON	6	Air Force; Acurex, Avco, United Research Technology
	ABLATIVE HEAT-SHIELD MATERIALS	6	Zoltek, Avco
	SLENDER NOSE TIPS	6	GE
	RADAR CROSS SECTION MODELING	6	Air Force; Atlantic Aerospace
	RE-ENTRY PARTICLE PLUME CODE	6	Air Force; Army (USASDC)
	MAGNESIUM-TEFLON FLARE CHEMISTRY	6	Air Force; Acurex, Morton-Thiokol, Rocketdyne
	OPTICAL REFERENCE SPHERE AND COATING	6	Air Force, SDIO; Army
	PASSIVE OPTICS TECHNIQUES	6	Army
	LWIR (Long Wave Infrared) SIGNAL PROCESSING	7	Air Force, Army
	LWIR SENSOR CALIBRATION	7	Air Force, Army
	TARGET REFLECTIVITY ANALYSIS — ANALYTIC MODEL AND CODE	7	Air Force; Surface Optics, Teledyne Brown Engineering

Mission	Technology/Product	Page Number	Sponsor; User Agency; Industry Developer
	DEBRIS MODELING	7	Nichols Research Corp., XonTech
	SCAN-TO-SCAN CORRELATION ALGORITHM	7	Nichols Research Corp., Teledyne Brown Engineering
	MISS DISTANCE ANALYTIC MODEL	7	Martin Marietta, SAIC
	GBR (Ground-Based Radar) DISCRIMINATION ALGORITHM	7	SDIO, Army; Raytheon
	HIGH RESOLUTION RADAR IMAGING	7	Air Force
Systems	COBRA DANE RADAR	8	Air Force; Raytheon
	COBRA JUDY RADAR	8	Air Force, Army; Raytheon
	OAMP (Optical Aircraft Measurements Program)	8	Army
	KREMS PROJECT	8	DARPA, Army; Navy, Air Force, NASA, NSF; TRW, XonTech, Ford Aerospace, Lockheed, GE, GTE, Avco, OTM
SATELLITE AND LASER COMMUNICATIONS		8	
Technology	SPATIAL ACQUISITION AND TRACKING	8	Perkin-Elmer
Techniques	FEP (FLTSAT EHF Package) AND EHF TEST-BED	9	Army, Navy, Air Force
	MDR (Medium Data Rate)/HDR (High Data Rate) COMMUNICATIONS	9	Air Force Space Systems Division; GE, TRW, Hughes
	MDR EHF TRANSMISSION WAVEFORMS	9	Air Force Space Systems Division
	STITCHWELD	10	Air Force; Moore System Stitchweld
	EHF DOWN-CONVERSION SCHEME	10	Air Force; TRW
	WEATHER COMPUTER PROGRAM	10	Air Force; Lockheed
Components	44/20-GHz DUAL-FREQUENCY HORN	10	Air Force; Alpha Industries, Raytheon
	20- and 44-GHz EARTH-COVERAGE HORNS	10	Air Force

Mission	Technology/Product	Page Number	Sponsor; User Agency; Industry Developer
	4-LENS MBA (Multiple-Beam Antenna)	10	Air Force
	WAVEGUIDE LENS MBA	10	Air Force; GE
	BEAM AREA COVERAGE MBA	10	Air Force; TRW
	ADAPTIVE EHF (44-GHz) UPLINK SATELLITE ANTENNA	10	Air Force Space Systems Division
	HIGH-POWER RELIABLE 20-GHz DOWNLINK ANTENNA/TRANSMITTER ASSEMBLY	11	Air Force Space Systems Division
Systems	LES (Lincoln Experimental Satellite) PROGRAM	11	Air Force, Army, Navy, DCA (Defense Communications Agency); Hughes, TRW, GE
	EHF NULLING SYSTEM	11	Air Force; TRW
	TATS (Tactical Transmission System)	11	Air Force; GTE Sylvania
	SCOTT ADM	11	Army; Magnavox, Steinbacher, Alpha Industries, Raytheon
	ADVANCED SCAMP (Single Channel Advanced MILSTAR Portable) TERMINAL	11	Army; Harris, MPC, Avantek
LASER COMMUNICATIONS		12	
Techniques	DIODE LASER POWER SUPPLY AND TEMPERATURE CONTROL	12	Air Force; Newport Research Corp.
Components	DOUBLE BALANCED MIXER FRONT-END	12	Air Force; Schwartz Electro-Optic
	LITE (Laser Intersatellite Transmission Experiment)	12	Air Force; Perkin-Elmer
Systems	COHERENT LASER COMMUNICATION SYSTEM	12	Air Force; AT&T, GTE
SPACE SURVEILLANCE		12	
Technology	RADAR IMAGING ANALYSIS	12	Air Force Space Command, Foreign Technology Division of Systems Command
Techniques	ELECTRO-OPTICAL SENSING	13	Air Force Space Command; Kentron
	COHERENT INTEGRATION	13	Air Force; GTE, GE

Mission	Technology/Product	Page Number	Sponsor; User Agency; Industry Developer
	PHASED ARRAY RADAR	13	Air Force Logistics Command
	ORBIT DETERMINATION	13	Air Force; GE, GTE
	TRAINING COURSES ON USE OF SURVEILLANCE RESOURCES	13	U.S. Space Command/Space Surveillance Center
	GEODSS SEARCH TECHNIQUES	13	U.S. Space Command; Kentron
	DPCA (Displaced Phase Center Antenna)	13	Air Force; Raytheon, GE, Martin Marietta
	INTACS (Integrated Network Tasking and Control Systems)	14	Air Force Space Surveillance Center
Components	SBV (Space-Based Visible) SURVEILLANCE	14	Air Force; Air Force Space Command
	PACS (Processing and Control System)	14	Air Force Electronic Systems Division
	DETECTION SIGNAL PROCESSOR	14	Air Force Space Systems Division; TRW
	LRIR (Long Range Imaging Radar)	14	Air Force
	DSNCP (Deep-Space Network Control Processor)	14	U.S. Space Command/Space Surveillance Center
	ISD (Interactive Scenario Designer)	14	U.S. Space Command/Space Surveillance Center
	UCTP (Uncorrelated Target Processor)	15	U.S. Space Command
Systems	GEODSS (Ground-Based Electro-Optical Deep-Space Surveillance System)	15	Air Force
SURFACE AND AIR SURVEILLANCE		15	
Technology	ULTRA-LOW SIDELOBE ANTENNA	15	Navy; Westinghouse
	CASCADED ADAPTIVE ARRAY	15	Navy
	MASR (Multiple Antenna Surveillance Radar)	15	Air Force; Raytheon, Grumman
Techniques	WAVEFORM GENERATOR	15	Air Force; Hewlett-Packard
	ADAPTIVE NULLING CONCEPTS	16	Navy; Raytheon, Westinghouse, Hughes

Mission	Technology/Product	Page Number	Sponsor; User Agency; Industry Developer
	ADAPTIVE NULLING ARCHITECTURE	16	Air Force; Raytheon, GE
	FOCUSED NEAR-FIELD TESTING	16	Air Force; Raytheon, GE
	SIGNAL PROCESSING ARCHITECTURE	16	Navy; XonTech, Westinghouse, Raytheon, Huges, DEC, Motorola
	SMI (Sample Matrix Inversion) CONVERGENCE	16	Navy
	ADAPTIVE SIDELOBE BLANKER	17	Navy
	MULTI-FREQUENCY LOW-ANGLE CLUTTER MODEL	17	Air Force, Army, Navy
	TERRAIN SPECIFIC RADAR PROPAGATION MODEL	17	Air Force; Government, industry
	SUPERRESOLUTION PROGRAM	17	Argo Systems, Hazeltine, E-Systems, Sanders, ITT, AIL Systems, AST
	ADC (Analog-to-Digital Converter) TEST-BED	17	Air Force; TRW, Westinghouse, Elsin, Tektronix, Analogic, Analog Devices
	CLASSIFICATION ALGORITHMS	17	Harry Diamond Laboratory, Teledyne Systems, Grumman, Lockheed
	AIR SURVEILLANCE	18	Air Force; SAIC; Spectral Sciences, Georgia Institute of Technology, Martin Marietta
Components	ADVANCED SIGNAL PROCESSOR	18	DARPA, Harry Diamond Laboratory; AIL/Eaton, Emerson
	PMP (Parallel Microprogramming Processor)	18	Air Force; FAA, DARPA, Army, Sandia National Laboratory
	ADVANCED AIRBORNE RADAR	18	Air Force
	FERM (Finite Element Radiation Model)	18	Air Force; DOD, defense industries
	UAV (Unmanned Aerial Vehicle) SIGNAL PROCESSOR	18	Harry Diamond Laboratory; AIL/Eaton

Mission	Technology/Product	Page Number	Sponsor; User Agency; Industry Developer
	BINARY OPTICS	18	Air Force, AFWL, DARPA, Army Night Vision and Electrooptics Laboratory, SDIO, Army/SDC; Hughes, Rockwell, Polaroid, Perkin-Elmer
AIR TRAFFIC CONTROL		19	
Techniques	MULTIPATH MODELING TOOLS	19	FAA, other industries
	MOVING TARGET DETECTOR	20	FAA; Westinghouse, Stein Associates
	TDWR (Terminal Doppler Weather Radar)	20	FAA; Raytheon
	NEXRAD (Next-Generation Weather Radar)	20	FAA, Air Force, National Weather Service, Naval Oceanography Command, Commerce Department-National Oceanic and Atmospheric Administration; UNISYS
	LINCOLN MLS (Microwave Landing System)	20	FAA, Federal Republic of Germany, United Kingdom
Systems	Mode S (Mode Select) BEACON SYSTEM	20	FAA; Westinghouse, Burroughs
	TCAS (Traffic Alert and Collision Avoidance System)	21	FAA; Honeywell, Collins, Bendix
ADVANCED ELECTRONICS TECHNOLOGY: SOLID STATE		21	
Techniques	ACCEPTOR DOPING OF HgCdTe (Mercury Cadmium Telluride)	21	Air Force; Raytheon
	TRI-ARC METHOD	21	Air Force; GE
	LASER PHOTODEPOSITION	21	Air Force; Micron Technology
	EXCIMER LASER LITHOGRAPHIC STEPPER	21	DARPA; Perkin-Elmer
	LASER DIRECT WRITE TECHNOLOGY	21	Air Force; Gould/AMI
	LARGE CROSSBAR SWITCH	21	Air Force; GTE
	DIAMOND ETCHING TECHNIQUE	21	NASA

Mission	Technology/Product	Page Number	Sponsor; User Agency; Industry Developer
	DIODE LASER ARRAYS	21	Air Force; TRW
	ANALOG FIBER OPTIC LINKS	22	Air Force
	BATTERY MATERIAL PROCESSING	22	Air Force; Battery Engineering
	X-RAY LITHOGRAPHY		Air Force; IBM, AT&T, Perkin-Elmer, Hampshire Instruments, Spire Corp.
	PROTON ISOLATION OF GaAs (Gallium Arsenide) DEVICES	22	Air Force
	LOW TEMPERATURE GaAs	22	Air Force; Hewlett-Packard, GE, Motorola, Celeritek
	MICROCHANNEL HEAT SINKS	22	AFWL; TRW, David Sarnoff Laboratories
	HYDROPLANE POLISHER	22	Air Force; Industry-wide
	GAS-SOURCE MBE (Molecular Beam Epitaxy)	23	DARPA
	SUPERCONDUCTOR RESONATOR TECHNIQUE	23	Army, Air Force, DARPA; Superconducting Technologies
Components	CCD (Charge-Coupled Device) SIGNAL PROCESSING CHIP	23	Air Force; Ford Aerospace, Stanford Telecommunications
	CCD FABRICATION TECHNOLOGY	23	Fairchild, Ford Aerospace, Reticon
	FOCAL PLANE ARRAYS	23	Air Force; Ford Aerospace
	BROADBAND FARADAY ISOLATOR	23	Navy; Isowave
	LOGIC DEVICE INTEGRATION	23	Hughes
	LNA (Low Noise Amplifier)	23	Adams Russell
	GaAs MONOLITHIC ATTENUATORS	24	Air Force; GE
	RF SWITCH DEVICES	24	Air Force; Adams Russell
	GaInAsP (Gallium Indium Arsenide Phosphide) DIODE LASERS	24	Air Force; Lasertron, AT&T
	GRAPHITE-EPOXY SANDWICH MIRRORS	24	Navy; Composite Optics
	LIGHTWEIGHT GRAPHITE-EPOXY TUBES	24	Navy; ALCOA

Mission	Technology/Product	Page Number	Sponsor; User Agency; Industry Developer
	SEMICONDUCTOR LASERS	24	Air Force, NSF
	CO_2 LASER TECHNOLOGY	24	Air Force; Apollo Lasers
	Co:MgF_2 (Cobalt Magnesium Fluoride) LASER	24	Air Force; Schwartz Electro-Optics
	Ti:Al_2O_3 (Titanium Aluminum Oxide) LASER	24	Navy; Schwartz Electro-Optics, Union Carbide, Spectra-Physics, Excel Technology
	SAW (Surface Acoustic Wave) DEVICES	25	Air Force
	DIAMOND TRANSISTORS	25	Office of Naval Research; Diamond Materials
	INTEGRATED OPTICAL WAVEGUIDE DEVICES	25	Air Force, NSF; Crystal Technology
	SAW CHIRP FILTER	25	Air Force, Navy; Texas Instruments, Hughes, TRW
	SAW/FET (Surface Acoustic Wave/Field Effect Transistor)	25	Air Force
	GALLIUM ARSENIDE PBTs (Permeable-Based Transistors)	25	Air Force; M/A-Com Linkabit
	RESONANT TUNNELING DEVICES	25	Hughes, AT&T, Texas Instruments
	CORNER-CUBE GaAs MIXER DIODE	25	DOE, Army; Millitech
Systems	CCD IMAGER TECHNOLOGY	26	Air Force; Rockwell, Hughes, TRW, SAIC, Kodak
	EXTERNAL CAVITY DIODE LASERS	26	AFWL; McDonnell Douglas, AT&T
	LONG PULSE LAMP PUMPED Nd:YAG (Neodymium Yttrium Aluminum Garnet) LASERS	26	Air Force, NSF; Quantel International
ADVANCED ELECTRONICS TECHNOLOGY: COMPUTERS		26	
Techniques	MULTIDOMAIN TARGET RECOGNITION	26	DARPA
	SLASH (Standard Linking Automation Shell)	26	Air Force, DARPA
	CCSIM (Call-by-Call Simulator)	26	Defense Communications Agency; GTE

Mission	Technology/Product	Page Number	Sponsor; User Agency; Industry Developer
	WIDEBAND SIGNAL DETECTION AND DIRECTION FINDING ALGORITHMS	27	DARPA; Lawrence Livermore Laboratory, Army Cold Regions Research Laboratory
Components	WAFER-SCALE TECHNOLOGY	27	DARPA; Westinghouse
	MUSE (Matrix Updating Systolic Experiment) WAFER	27	Air Force; Westinghouse, U.S. Army Strategic Defense Command; Star Technologies
	INTERFACE BOARDS	27	U.S. Army Strategic Defense Command, Star Technologies
Systems	ETC (Expert Tech Controller)	27	Air Force RADC/DC; Structured Software and Systems
	ACOUSTIC TRACKING ALGORITHMS	27	DARPA, Army; SAIC
	STC (Sinusoidal Transform Coder)	27	DARPA; Voice of America; CYLINK
	SINUSOIDAL ANALYSIS/SYNTHESIS SPEECH ENHANCEMENT SYSTEM	28	RADC, Voice of America
	PACKET VOICE TERMINAL	28	DARPA, Navy; ACC
	COMPACT LPC (Linear Predictive Coder)	28	NSA; Motorola, AT&T, RCA
	WORDSPOTTING	28	NSA
HIGH ENERGY LASER BEAM CONTROL TECHNOLOGY		28	
Techniques	LASER DIAGNOSTICS	28	Army-White Sands Missile Range High Energy Laser Facility and site contractor O&M
	DIODE LASER MONITORING AND SPECTROSCOPY	29	Air Force; Laser Analytics, Los Alamos National Laboratory
	OPTICAL CHIRP COMPRESSION	29	DARPA, Air Force; Spectra-Physics, Government laboratories
	BEAM CONTROL TECHNOLOGY	29	Army/SDC; Lockheed
	BEAM PATH CONDITIONING SYSTEMS	29	Army; Perkin-Elmer, JAYCOR

Mission	Technology/Product	Page Number	Sponsor; User Agency; Industry Developer
	CONTROL THEORY DEVELOPMENT	29	Army; Harris
Components	SATELLITE ORBIT COMPUTATIONS	29	Army-White Sands Missile Range High Energy Laser Facility; Hughes, UNISYS
	DEFORMABLE MIRROR DRIVER CIRCUITS	29	Army; Lockheed
	FAST STEERING MIRROR CONTROLS	29	Army; United Technologies Optical Systems Division
Systems	AUXILIARY BEAM DIRECTOR	30	Army, Air Force; Army-White Sands Missile Range; Dynaelectron

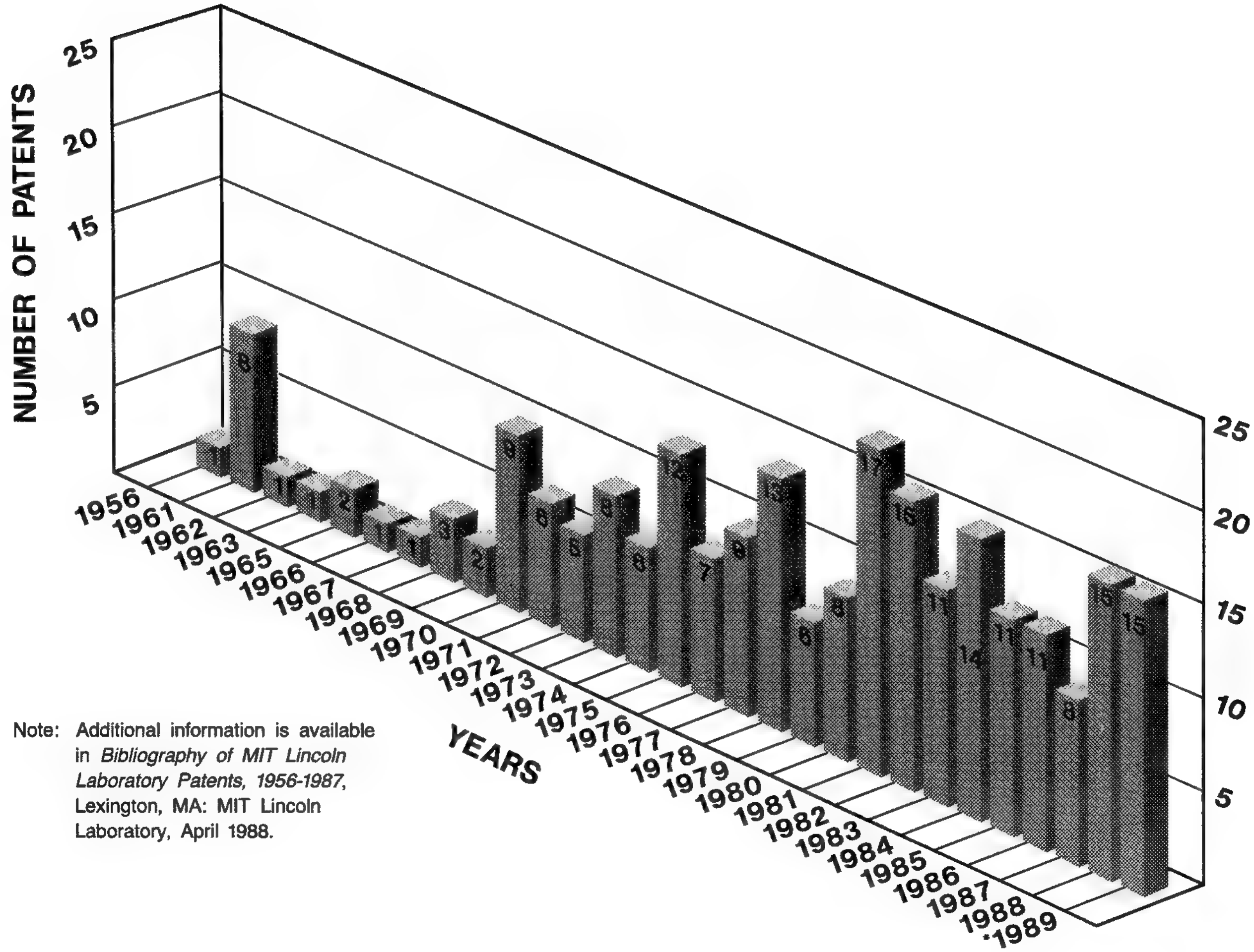
4.2 EARLIER ACTIVITIES (1953-1969)

STRATEGIC OFFENSE AND DEFENSE		30	
Techniques	RE-ENTRY PHYSICS PROGRAM	30	ARPA
Systems	SAGE	30	Air Force; IBM, Burroughs, Rand
	DEW (Distant Early Warning) LINE	30	Air Force
	BMEWS (Ballistic Missile Early Warning System)	30	Air Force; NASA, Canada
	AICBM (Anti-Intercontinental Ballistic Missile)	30	Air Force
	PRESS (Pacific Range Electromagnetic Signature Studies) PROJECT	31	DARPA, Army; Sandia National Laboratory; TRW, XonTech, Ford Aerospace, Lockheed, GTE, Avco
	AMRAD (ARPA Measurements Radar)	31	ARPA; White Sands Missile Range
SATELLITE COMMUNICATIONS		31	
Technology	PROJECT MERCURY	31	NASA; Western Electric
Techniques	WEST FORD	31	Air Force
Systems	LES (Lincoln Experimental Satellites)	31	Air Force; TRW, GE, Ford Aerospace

Mission	Technology/Product	Page Number	Sponsor; User Agency; Industry Developer
COMPUTER SYSTEMS		32	
	MAGNETIC CORE MEMORY	32	Navy, Air Force; IBM and other manufacturers
	WHIRLWIND	32	Office of Naval Research
	AN/FSQ-7	32	Air Force
	TX-0	32	Air Force; DEC
	TX-2	32	Air Force, DARPA
	CG-24	32	Air Force
	LINC (Lincoln Instrument Computer)	32	Air Force
	LX-1	32	ARPA, Air Force
	FDP (Fast Digital Processor)	32	ARPA
TACTICAL TECHNOLOGY		33	
Technology	MTI (Moving Target Indicator) RADARS	33	Army
Techniques	ECCM (Electronic Counter-Countermeasures)	33	Air Force
	EMITTER HOMING PROGRAM	33	Air Force
Components	CCD MATCHED FILTER	33	Air Force; RCA, Ford Aerospace, Fairchild
MISCELLANEOUS TECHNOLOGY		33	
	PHOTOVOLTAIC/THERMAL COLLECTORS	33	Department of Energy (DOE), Air Force, Solar Energy Research Institute
	GALLIUM ARSENIDE SOLAR CELLS	33	Department of Energy (DOE)
	SEISMIC DISCRIMINATION	34	ARPA, Nuclear Regulatory Commission, NSF
	EASYPLOT	34	Spiral Software
	THERMOMAGNETIZATION THEORY OF FERRIMAGNETS	34	Army, ARPA

Mission	Technology/Product	Page Number	Sponsor; User Agency; Industry Developer
	THE VSM (Vibrating Sample Magnetometer)	34	Air Force; Princeton Applied Research
	SYNTHESIS OF LANTHANUM COPPER OXIDE FOR SUPER-CONDUCTIVITY	34	Air Force

5. APPENDICES



Note: Additional information is available in *Bibliography of MIT Lincoln Laboratory Patents, 1956-1987*, Lexington, MA: MIT Lincoln Laboratory, April 1988.

* 1989 Incomplete

Patents issued to MIT Lincoln Laboratory

VISITORS TO MIT LINCOLN LABORATORY

	1986	1987	1988
Classified Visits			
Industry	2,762	2,233	1,890
University	61	61	61
U.S. Air Force	537	727	645
U.S. Army	164	223	118
U.S. Navy	205	218	99
Government	1,175	1,092	1,228
Non-profit	115	137	34
Consultant	26	8	0
Foreign	0	75	44
MCS Study	0	2,552	0
Subtotal	5,048	7,326	4,119
Unclassified Visits			
Industry	9,161	9,701	7,260
University	1,565	1,929	1,648
U.S. Air Force	678	510	650
U.S. Army	118	71	70
U.S. Navy	148	93	37
Government	608	705	305
Non-profit	243	229	152
Consultant	784	269	312
Foreign	207	667	460
Subtotal	13,512	14,174	10,894
TOTAL	18,560	21,500	15,013

SPIN-OFF COMPANIES FROM MIT LINCOLN LABORATORY*

ADAMS ASSOCIATES — (Now Keydata Corporation)
Date Founded: 1954
Products and Services: Provider of business data processing and on-line services for manufacturers and distributors.

ADVANCED COMPUTER TECHNIQUES CORPORATION
Date Founded: 1962
Products and Services: Computer systems development and computer consulting; provides data processing services and computer analysis.

AMERICAN POWER CONVERSION CORPORATION
Date Founded: 1981
Products and Services: Wholesale peripheral computer equipment and small uninterruptible power source computer systems.

AMTRON CORPORATION
Date Founded: 1956
Products and Services: Radio frequency generators.

APPLICON, INC. — (Now a CAD/CAM subsidiary of Schlumberger Technology Corp.)
Date Founded: 1969
Products and Services: Software design.

ARCON CORPORATION
Date Founded: 1969; Inc. 1961
Products and Services: Developer of computer programs.

ASCENSION TECHNOLOGY, INC.
Date Founded: 1986
Products and Services: Consulting in electric power systems and distributed photovoltaic systems.

ATLANTIC AEROSPACE ELECTRONICS CORPORATION
Date Founded: 1985
Products and Services: Radar surveillance systems and electronic countermeasures.

BOGART-BROCINER ASSOCIATES
Date Founded: 1978
Products and Services: Reference and research services specializing in the areas of science, technology, and medicine.

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* Additional information is available in *Spin-Off Companies from MIT Lincoln Laboratory,* Lexington, Mass.: MIT Lincoln Laboratory (April 1989).

CHRONAR TRISOLAR, INC. — (Sold to Chronar Corporation in 1987)
Date Founded: 1980
Products and Services: Stand-alone solar power systems, solar water pumps, and solar electric systems.

CLARK, ROCKOFF AND ASSOCIATES
Date Founded: 1985
Products and Services: Consulting in systems design and patents.

COMPUTER CORPORATION OF AMERICA — (Now a subsidiary of Crowntek, Inc., Canada)
Date Founded: 1965
Products and Services: Developer and marketer of database-management software and other systems software, as well as some applications development software.

CORPORATE TECH PLANNING, INC.
Date Founded: 1969
Products and Services: Data systems design and implementation.

DIGITAL COMPUTER CONTROLS, INC.
Date Founded: 1969
Products and Services: Computer controls.

DIGITAL EQUIPMENT CORPORATION
Date Founded: 1957
Products and Services: Manufacturer of general-purpose computers and developer of related software.

ELECTRO-OPTICAL TECHNOLOGY, INC. — (Merged with I.L. Med, 1988)
Date Founded: 1985
Products and Services: Laser components and systems.

ELECTRONIC SPACE STRUCTURES, INC. — [Now Electronic Space Systems Corporation (ESSCO)]
Date Founded: 1961
Products and Services: Radomes and synergized antenna systems.

EPITEK CORPORATION
Date Founded: April 1983
Products and Services: Vapor phase epitaxial growth of mercury cadmium telluride.

EVANS & SUTHERLAND COMPUTER CORPORATION
Date Founded: 1968
Products and Services: 3-D graphic solid object modeling software, graphics terminals, aircraft computer systems, and 3-D graphic molecule modeling software.

FRONTIER TECHNOLOGY, INC.
Date Founded: 1986
Products and Services: Research and development of hardware and software, silicon compiler; conducts technical seminars.

FWS ENGINEERING
Date Founded: 1982
Products and Services: Consultant in electronic and communication instruments and power systems.

HERMES ELECTRONICS, INC. — (Acquired by Itek Corporation in 1960)
Date Founded: 1956
Products and Services: Electronics

HH CONTROLS, INC.
Date Founded: 1963
Products and Services: Manufacturer of electro-optical equipment.

INFORMATION INTERNATIONAL, INC.
Date Founded: 1962
Products and Services: Computer-based electronic optical systems which generate finished pages containing text drawings and photographs.

INTERACTIVE DATA CORPORATION — (Now a subsidiary of Data Services Corporation)
Date Founded: 1988
Products and Services: Provider of on-line financial data and developer of database software.

JANIS RESEARCH COMPANY, INC.
Date Founded: 1960
Products and Services: Cryogenic laboratory apparatus.

JOHN ACKLEY CONSULTANTS
Date Founded: 1976
Products and Services: Consulting in computer-related products and services; implementing computer systems.

KOPIN CORPORATION
Date Founded: 1984
Products and Services: Developer and supplier of advanced composite, application-specific wafers for the next generation of high-performance semiconductors and integrated circuits.

KULITE SEMICONDUCTOR PRODUCTS, INC.
Date Founded: 1959
Products and Services: Sensors, transducers, and transmitters.

LASER ANALYTICS, INC. — (Now Laser Analytics, a CAD Division of Spectra-Physics, Inc.)
Date Founded: 1975
Products and Services: Sales and service of lasers used in building construction.

LASERTRON, INC.
Date Founded: 1980
Products and Services: Long wavelength lasers, LEDs, pin detectors, and pinFET preamplifiers for the fiber optics industry.

L.J. RICARDI, INC. — (Now a subsidiary of EMS Inc.)
Date Founded: 1984
Products and Services: Satellite communication analysis.

LOUIS SUTRO ASSOCIATES
Date Founded: 1982
Products and Services: Consultant in engineering design.

MAN LABS, INC.
Date Founded: 1960
Products and Services: Research, development, and testing in materials science.

M.D. FIELD COMPANY
Date Founded: 1960
Products and Services: Consultant in systems engineering and requirements analysis.

MICRILOR, INC.
Date Founded: 1984
Products and Services: Research and development on signal processing for the Department of Defense.

MICRO-BIT CORPORATION — (Acquired by Control Data Corporation)
Date Founded: 1969
Products and Services: Research in electron beam memory

MICRO COMPUTER SOFTWARE, INC.
Date Founded: 1981
Products and Services: Developer and supplier of software for personal computers.

M.I.T. FRANCES BITTER NATIONAL MAGNET LABORATORY
Date Founded: 1960
Products and Services: Research and development in science and engineering in areas involving magnetic fields.

MITRE CORPORATION
Date Founded: 1958
Products and Services: Research in command systems, space surveillance systems, tactical systems, applications of data processing, radars, and communications.

NETEXPRESS, INC. — (Includes Net Express Systems, Inc. and Net Express Communications, Inc.)
Date Founded: 1983
Products and Services: Document handling, retrieval, and storage equipment; document communications network, including hardware and software.

PHOTON, INC.
Date Founded: 1984
Products and Services: Consulting, and research and development of electronics hardware and computer software.

QEI, INC.
Date Founded: 1966
Products and Services: Computer and information systems.

SCHWARTZ ELECTRO-OPTICS, INC.
Date Founded: 1985
Products and Services: Designer and manufacturer of medical, scientific, and military laser equipment.

SIGNATRON, INC. — (Subsidiary of Sundstrand Corporation)
Date Founded: 1962
Products and Services: Development and analysis of specialized radar and communication systems and software.

SOLSTICE ENGINEERING
Date Founded: 1985
Products and Services: Engineering consulting for utilities.

SPARTA, INC. — (Lexington Branch)
Date Founded: 1980
Products and Services: Engineering services, experimental research in optics and applied physics.

TELENET COMMUNICATIONS, INC. — (Now Telenet Communications Corporation, a U.S. Sprint Company)
Date Founded: 1973
Products and Services: Data communications products and services.

TRANSDUCER PRODUCTS, INC.
Date Founded: 1963
Products and Services: Manufacturer of ultrasonic crystals.

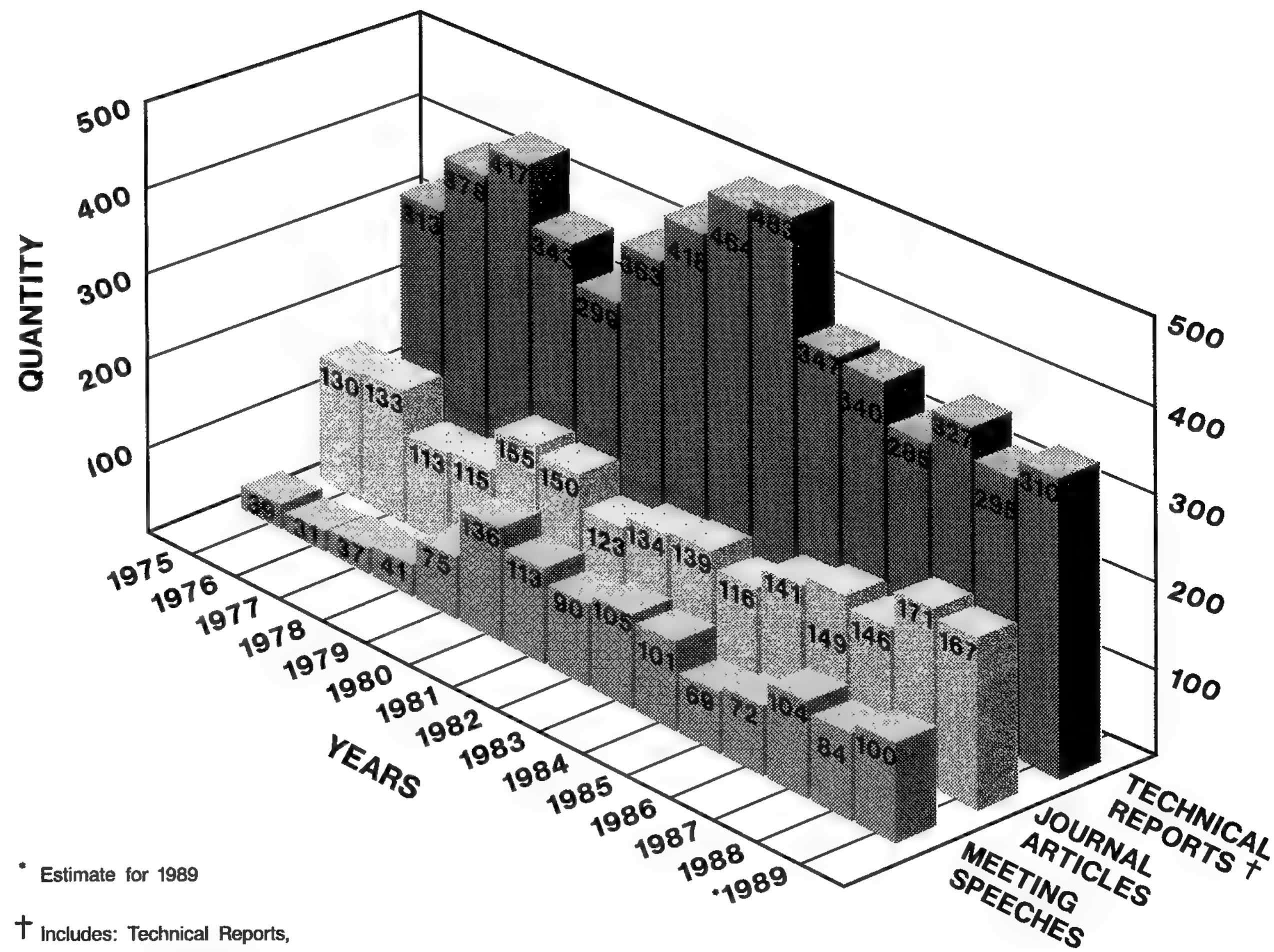
TYCO LABORATORIES, INC. — (Now Mobil Solar Energy Corporation)
Date Founded: 1969
Products and Services: Designer of photovoltaic devices.

WOLF RESEARCH & DEVELOPMENT, INC.
Date Founded: 1954
Products and Services: Provider of digital computer analysis, programs, and associated services for the Army, Navy, Air Force, and NASA.

XONTECH, INC.
Date Founded: 1980
Products and Services: Research and systems engineering in radar, space, optics, communications, and computer science.

ZEOPOWER COMPANY
Date Founded: 1978
Products and Services: Solar cooling equipment, solar collectors, and AC heat pump.

5 April 1990



* Estimate for 1989

† Includes: Technical Reports,
Progress Reports,
Project Reports

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6. LIST OF ACRONYMS

AAWS-M	Advanced Antiarmor Weapon System-Medium
ACC	Advanced Computer Communications
ADC	Analog-to-Digital Converter
ADM	Advanced Development Model
AFSSD	Air Force Space Systems Division
AFWL	Air Force Weapons Laboratory
AICBM	Anti-Intercontinental Ballistic Missile Program
ALCOR	ARPA Lincoln C-Band Observables Radar
ALTAIR	ARPA Long-Range Tracking and Instrumentation Radar
AMRAD	ARPA Measurements Radar
AMTI	Airborne Moving Target Indicator
APGM	Advanced Precision Guided Munitions
ARPA	Advanced Research Projects Agency
ASR	Airport Surveillance Radar
ASSOP	Advanced Surveillance System Observation Processor
ATR	Automatic Target Recognition
BMD	Ballistic Missile Defense
BMEWS	Ballistic Missile Early Warning System
BSD	Ballistic Systems Division
BSTS	Boost Surveillance and Tracking System
CAD	Computer-Aided Design
CASPADS	Computer Assisted Space Analysis and Data Systems
CCD	Charge-Coupled Device
CCSIM	Call-by-Call Simulator
CFAR	Constant False Alarm Rate
CMAFS	Cheyenne Mountain Air Force Station
DARPA	Defense Advanced Research Projects Agency
DCA	Defense Communications Agency
DEC	Digital Equipment Corp.
DEW	Distant Early Warning
DOE	Department of Energy
DOT	Designating Optical Tracker
DPCA	Displaced Phase Center Antenna
DSCS	Defense Satellite Communications System
DSN	Defense Switched Network
DSNCP	Deep-Space Network Control Processor
DSP	Digital Signal Processing

ECCM	Electronic Counter-Countermeasures
EHF	Extremely High Frequency
ETAS	Elevated Target Acquisition System
ETC	Expert Tech Controller
FAA	Federal Aviation Administration
FDP	Fast Digital Processor
FEL	Free Electron Laser
FEP	FLEETSAT EHF Package
FERM	Finite Element Radiation Model
FET	Field Effect Transistor
FLIR	Forward Looking Infrared
FLTSAT	FLEETSAT
GBR	Ground-Based Radar
GEODSS	Ground-Based Electro-Optical Deep-Space Surveillance System
GTS/ETS	GEODSS Test System/Experimental Test System
HDR	High Data Rate
HF	High Frequency
HOE	Homing Overlay Experiments
ICBM	Intercontinental Ballistic Missile
IDCSP	Initial Defense Communications Satellite Program
IF	Intermediate Frequency
INTACS	Integrated Network Tasking and Control Systems
IRAR	Infrared Airborne Radar
IRMS	Infrared Measurement System
ISD	Interactive Scenario Designer
JRSVC	Jam-Resistant Secure Voice Communications
JSTARS	Joint Stand-Off Target Acquisition Radar System
KDS	KREMS Discrimination System
	Kwajalein Discrimination System
KREMS	Kiernan Re-entry Measurement Site
LASA	Large Aperture Seismic Array
LATS	Longwave Infrared Advanced Technology Seeker
LDR	Low Data Rate
LDS	Lincoln Discrimination System
LEASAT	Lease Satellite
LES	Lincoln Experimental Satellite
LINC	Lincoln Instrument Computer
LITE	Laser Intersatellite Transmission Experiment

LNA	Low Noise Amplifier
LPC	Linear Predictive Coding
LRIR	Long Range Imaging Radar
LWIR	Long Wavelength Infrared
MASR	Multiple Antenna Surveillance Radar
MBA	Multiple Beam Antenna
MBE	Molecular Beam Epitaxy
MDR	Medium Data Rate
MLS	Microwave Landing System
MMW	Millimeter Wave
Mode S	Mode Select Beacon System
MSX	Midcourse Space Experiment
MTI	Moving Target Indicator
MUSE	Matrix Updating Systolic Experiment
NEXRAD	Next-Generation Weather Radar
NFL	New Foreign Launches
NOMAC	Noise Modulation and Correlation
NORAD	North America Air Defense Command
NSA	National Security Agency
NSF	National Science Foundation
NVL	Night Vision Laboratory
OAMP	Optical Aircraft Measurements Program
OSC	Optical Signatures Code
PACS	Processing and Control System
PBT	Permeable-Based Transistor
PMP	Parallel Microprogramming Processor
PRESS	Pacific Range Electromagnetic Signature Studies
RADC	Rome Air Development Center
RF	Radio Frequency
RPV	Remotely Piloted Vehicle
RSO	Resident Space Object
RST	Radar Surveillance Technology
SAC	Strategic Air Command
SAGE	Semi-Automatic Ground Environment
SAW	Surface Acoustic Wave
SAW/FET	Surface Acoustic Wave/Field Effect Transistor
SBV	Space-Based Visible
SCAMP	Single Channel Advanced MILSTAR Portable Terminal

SCOTT	Single Channel Objective Tactical Terminal
SDC	Strategic Defense Command
SDIO	Strategic Defense Initiative Organization
SEKE	Spherical Earth with Knife-Edges
SFDR	Spurious-Free Dynamic Range
SIGINT	Signal Intelligence Technology
SLASH	Standard Linking Automation Shell
SMI	Sample Matrix Inversion
SPADOC	Space Defense Operations Center
SSC	Space Surveillance Center
SSTS	Space Surveillance Tracking System
STC	Sinusoidal Transform Coder
STU-III	Secure Telephone Unit-III (third generation)
TACCAR	Time Averaged Clutter Coherent Airborne Radar
TACSAT	Tactical Satellites
TATS	Tactical Transmission System
TCAS	Traffic Alert and Collision Avoidance System
TDWR	Terminal Doppler Weather Radar
TRADEX	Target Resolution and Discrimination Experiment (radar)
TWTA	Traveling Wave Tube Amplifier
UAV	Unmanned Aerial Vehicle
UCTP	Uncorrelated Target Processor
UFO	UHF-Follow-On
UHF	Ultra-High Frequency
USASDC	U.S. Army Strategic Defense Command
UTOS	United Technologies Optical Systems
VHF	Very High Frequency
VHSIC	Very High Speed Integrated Circuit
VOA	Voice of America
VSM	Vibrating Sample Magnetometer
VUE	Visible Ultraviolet Experiment

REPORT DOCUMENTATION PAGE

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MIT Lincoln Laboratory's programs span the full range of technological development: basic research, components and subsystems, feasibility determination, system development, and demonstration. This report provides statistics and brief descriptions of the various technology transfer activities of the Laboratory.

14. SUBJECT TERMS

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dual-use technologies	computers	medical applications	solid state physics
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